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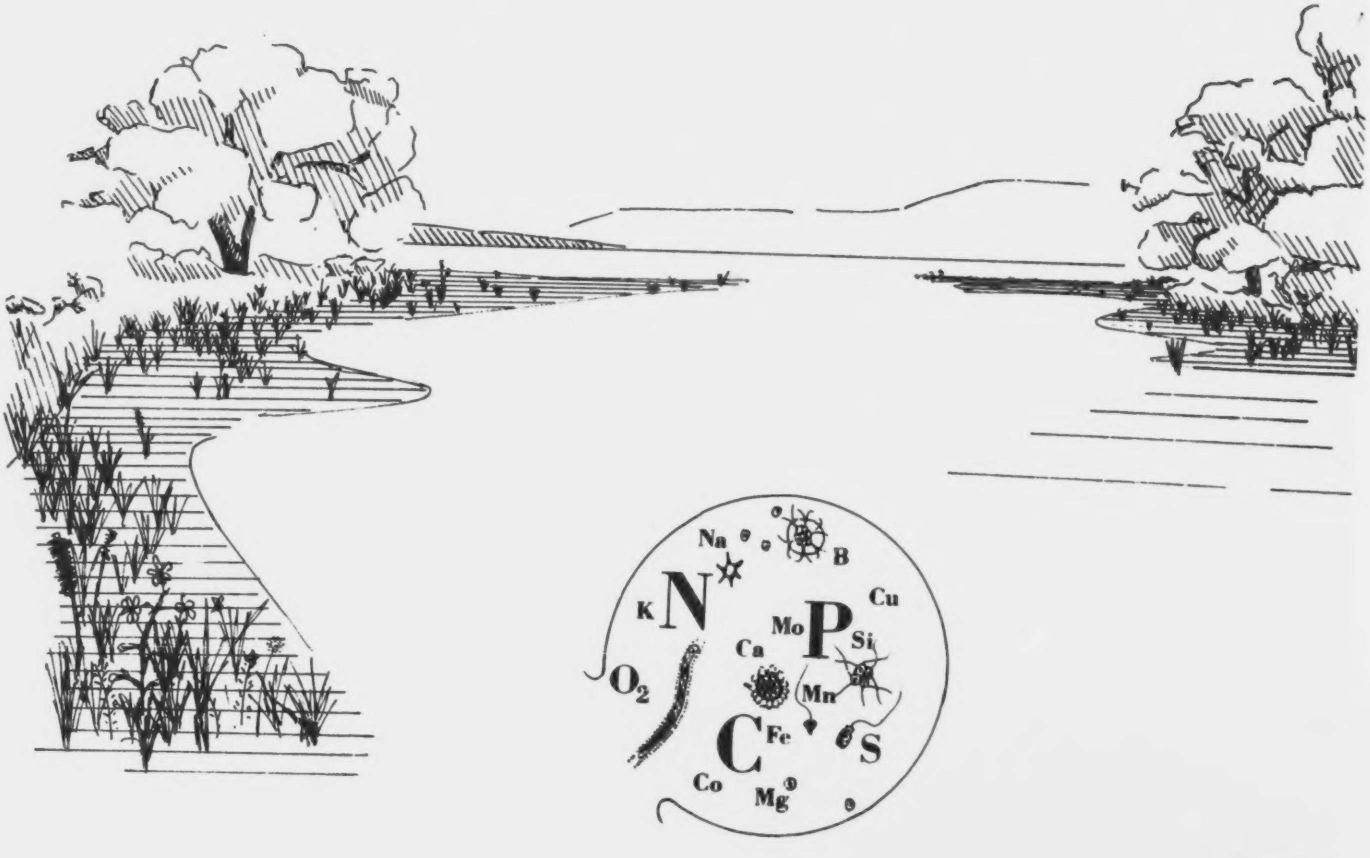
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g/sq m-year

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Land use patterns and population characteristics were determined photographically and N and P budgets estimated. Using multiple regression and canonical analysis, several significant relationships were found between lake trophic state, lake basin, land use, and population characteristics. In general, trophic state of lakes can be expressed as a simple relationship incorporating N and P influx rates. (Authors)

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Melrose (Florida)

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EUTROPHICATION FACTORS IN NORTH CENTRAL FLORIDA LAKES

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Office of Research and Monitoring
Environmental Protection Agency

Project # 16010 DON

February 1972

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ABSTRACT

A small Florida lake has been receiving a regimen of nutrient addition equivalent to 500 mg/m^3-yr N and 43 mg/m^3-yr P since 1967. Data has been accumulated through 1969. The effect on the lacustrine ecosystem of various biogenes includes production by primary producers, species diversity of plankton and certain production estimates at the secondary trophic level using natural populations of planktivorous fish. Plankton production using isotopic carbon is ca. 58 grms/m^2-yr. Species diversity is slowly changing to a mixed chlorophycean and yellow-green. Biomass of benthic green filamentous types has increased slightly. Nutrient addition has had little influence on zooplankton production.

Related studies on 53 other regional lakes have been done using a multi-dimensional hybrid concept as defined by several trophic state indicators. This trophic state index has provided a means for ranking the lakes on an arbitrary scale. Cluster analysis utilizing pertinent characteristics resulted in classification of other lakes.

Land use patterns and population characteristics were determined photographically and N and P budgets estimated. Using multiple regression and canonical analysis, several significant relationships were found between lake trophic state, lake basin, land use, and population characteristics. In general, trophic state of lakes can be expressed as a simple relationship incorporating N and P influx rates.

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SECTION I

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Anderson-Cue Lake has been enriched with nutrients and sewage since March, 1967. Lake response during this period has been negligible for most of the routine chemical and biological parameters. As the data show, using the mean for all years, a significant difference does occur for chlorophyll a, but among no other parameters. We are beginning to visually observe large increases in the periphyton especially attached filamentous chlorophyceae. These are species of Mougeotia, Mougeotopsis and Spirogyra predominantly. Extensive submersed growths of these organisms have been blanketing the littoral zone for the past 18 months with a periodicity from about April through early July. The crop declines in late summer. Although as yet these are qualitative observations we are fairly confident they represent a significant algal response to enrichment. It appears that at the present level of eutrophy in Anderson-Cue Lake production estimates of only phytoplankton may be misleading and that more reliability regarding the effects of lake enrichment may be gained by examining the productivity of other segments of the plant community as well. This means that Florida lakes of this type undergo a subtle alteration in the early stages of eutrophication which do not respond to the usual methods of detection. Examinations of other primary producer compartments would be fruitful in this respect.

2. Trophic state indices can be established in a quantitative manner for lakes in this geographic area. The value of being able to determine a lake's trophic state is far reaching in establishing future quality standards for surface waters. Whether or not the indices are completely applicable to lakes in other geographic areas is not known at the present time. However, preliminary trials indicate good correlation.

3. Results from studies of the second trophic level have shown the mean value to be 50 k cal m^{-2} $year^{-1}$. This amount is within the expected range for lakes exhibiting oligotrophic characteristics. Thus far effects of enrichment on the zooplankton have been minimal.

4. Attempts to use littoral zooplankton as indicators of trophic state must be carefully carried out to reduce masking effects produced by other variables. In this study fluctuations in lake level obscured changes in the species composition and diversity of zooplankton induced by eutrophication. Primary production and temperature are among the most important environmental factors related to reproduction of littoral zooplankton. Correlations between population density and primary production most likely could be improved if the organic matter contribution of periphyton was considered.

Recommendations

This three year study was composed of background data and nutrient enrichment information. In particular, the TSI (Trophic State Index) has provided a mathematical formulation of lake eutrophication. The experimental lake has shown practically no change during the nutrient enrichment program. Basically, a review of the three year data produced one question, "What ecological compartment has been significantly affected by the N, P and sewage additions?" Only two alternatives appear possible: (1) the additives were readily absorbed by the sediment and/or (2) the additives were utilized by the plants acting as a biological pump to remove the nutrients from the sediment. Neither of these possibilities has been investigated.

Generally, primary production rates are based exclusively on the phytoplankton. In determining trophic states such a procedure appears to be misleading since there are other photosynthetic compartments which need to be considered. For example, periphyton and macrophytes may proliferate in the littoral zone when the influx of nutrients increases. Increased growths of these plants have been observed in Anderson-Cue Lake and likely are a result of the enrichment regimen.

Sediment analyses are not normally a parameter of water quality surveys. However, the history of lakes have been revealed by core sampling as an entity. While the past conditions of Anderson-Cue are not of particular interest at this time, the role of nutrient exchange and benthic algal growth in the sediment-water interface has emerged as a major point of concern in attempting to forecast early warning signals of lake deterioration.

Thus, the above discussion brings forth the recommendation of continued study of these lakes by looking at new areas where the first warning signs of degradation may be observed.

Specifically, this study showed Anderson-Cue to be phosphorous limited. Recent investigations at the EPA facility in Athens, Georgia, indicate carbon as another enrichment parameter. Carbon content analysis in the Anderson-Cue community would provide much needed information. Additionally, the natural nutrient input to these lakes must be defined. So far only rain water has been examined.

SECTION II

INTRODUCTION

Florida has a vast and valuable resource of fresh water considering the springs and nearly 8,000 (greater than one acre) lakes found within the state. Practically all of these surface waters are useful in a recreational sense and for this reason Florida appeals greatly to tourists everywhere within this country and Canada. Fishing, boating and various contact water sports are enjoyed by both residents and out-of-state visitors throughout the year. Therefore, the conservation of this fresh-water resource is most important to the state's economy.

However, since water is so intimately involved in the total well being of the environment, impairment of aquatic systems in varying degrees will affect all the biota including man within a particular ecosystem. Essentially, the water quality of lakes and other fresh-water resources mirrors the status of the total environment.

Over the years, Florida lakes have been enriched gradually with nutrient salts from the land. Encroaching urbanization and intensive agricultural practices have, however, increased nutrient addition to lakes on an unprecedented scale in recent years. This enrichment has accelerated the eutrophication of surface water thereby shortening the lives of lakes and generally impairing the quality of the water.

This problem, which can be reflected nationally, is acute in Florida. The shallow lake basins, long hours of sunlight and mild winter temperatures are some of the factors which make surface water particularly susceptible to the effects of enrichment and lead to sustained algal blooms throughout the year. The most classic example in Florida is Lake Apopka near Orlando. This is a 30,000-acre lake (12,145 hectares) which has been extensively enriched by fertilizers from bordering citrus and winter vegetable farms, municipalities, and citrus processing plants. A hyacinth eradication program employing herbicides over the last 20 years has left a flocculant bottom layer of undecomposed plant residues. These unconsolidated sediments according to a recent Federal Water Quality Administration report (1968) cover 90 percent of the lake bottom. Fish reproduction in Lake Apopka is prevented by the lack of suitable areas for spawning and by a persistent anaerobic environment.

A similar process is occurring in many other lakes within the state. Although the visible effects of eutrophication are well documented, very little real knowledge exists regarding the interplay of environmental parameters during lake enrichment. Ultimately management systems for whole drainage basins must be devised if the eutrophication problem is to be dealt with effectively. First, however, it is necessary to understand eutrophication in quantitative terms and in part to find the most effective combinations of enriching substances and determine how these relate for example, to the physical environment of lake morphology, climate and various edaphic factors. The present level of knowledge relative to cycling of biogenic materials is primitive and more experimental work is badly needed in this area. Recent work by Kerr et al (1970) may shed some insight on this problem. Ultimately to offer the maximum use of a lake to those living within the basin we must know what enrichment stress can be placed on surface water without measurably impairing its quality.

This can be brought about only by long-term research. Projects such as described herein, using whole lakes as experimental units, are few in this country. More are needed especially in varying geographic locations if we are to understand completely the eutrophication process.

The site for most of this study was in sandy, scrub-oak terrain near Melrose, Florida, about 25 miles east of Gainesville. There are numerous lakes in this area. Two of these (Anderson-Cue Lake and McCloud Lake) located on private property were selected through the cooperation of the owners. The isolated location of these lakes assured freedom from outside interference and urban or agricultural influence. Considerable effort was exerted in 1966 to establish a field station at the lake site and to install appropriate instrumentation. Background data on the chemistry and biology of the lakes were obtained in order to be certain of their similarity and trophic state. Nutrient enrichment of Anderson-Cue Lake has been continuous since March, 1967, and during this time both routine monitoring and special studies have been carried out in the two lakes comprising the experimental system.

In 1968 eutrophication research was extended to other lakes of various types and exhibiting varying trophic stages in the north central Florida area. For comparative purposes eutrophic lakes in the Oklawaha chain were also included.

Useful information is gained from programs of this kind since it has helped point the way to the development of a realistic index of trophic state for Florida lakes. In addition valuable base line information is obtained concerning water quality in north central Florida. From studies of this kind will emerge patterns for lake management.

Since lakes are slow to change, a considerable lag may ensue before lakes respond to restorative measures. Therefore, it is essential to regulate the pollution stress on lakes so as to maintain a desirable level of water quality at a stage where preventive measures will suffice. Hopefully ecosystem management models of whole lake basins will provide the means to accomplish these objectives.

SECTION III

RATE OF NUTRIENT ADDITION TO ANDERSON-CUE LAKE

Previous Fertilization Studies

One approach to studying eutrophication is to artificially enrich (eutrophy) a lake at a controlled rate and measure all the parameters which define trophic state. The problem then becomes a matter of relating the response of a lake (in terms of trophic structure) to the degree and rate of nutrient enrichment. The lake thus serves as a general model for the process; this approach has been used in the present study. Intentional fertilization of lakes for scientific purposes is not a new concept. Stewart and Rohlich (1967) recently reviewed previous experiments on lake fertilization. Einsele (1941) reported one of the first experiments on lake fertilization. He applied slug doses of superphosphate to a small German lake in 1937 and 1938. Temporary increases in the phytoplankton of the lake were found but the lake soon returned to normal. A number of investigators (e.g. Ball, 1948a, b; Langford, 1950; Nelson and Edmondson, 1955; Hooper and Ball, 1964) have attempted to increase the productivity of fish ponds by adding fertilizer. These attempts have had only moderate success. In most fertilization experiments, nutrients have been added in high slug doses rather than continuously. While temporary effects have been noted, the ponds or lakes usually returned to their original conditions in short periods of time.

Induced circulation by aeration or actual pumping of hypolimnion water into the epilimnion has been proposed by Hasler (1957) and Hooper _et al_ (1952) to render nutrients within a lake more available to phytoplankton. However, unless the sediments were actually disturbed by aeration, the long-term effect of this process would seem to be the reverse of that intended. Aeration would tend to keep the hypolimnion oxygenated and maintain an oxidized microzone at the sediment water interface which decreases the release of nutrients from the sediments.

Nutrient Loading Rates Into the Experimental Lake

Because of the nature and purpose of previous fertilization efforts, results from these studies are not directly applicable to the problem of cultural eutrophication. Man-induced eutrophication is characterized by a more or less continuous addition of nutrients to a lake from such sources as sewage effluent and urban and agricultural runoff, while most previous fertilization attempts have used sporadic or one-time applications of fertilizer. Generally, sufficient background data were obtained to describe the trophic state of a lake and its natural temporal variations. The study reported here is viewed as a long-term effort to follow the effects of a controlled nutrient input on a lake's trophic state. Two small lakes are involved; one lake is serving as a control and the other lake is being artificially enriched by continuous and controlled addition of nutrients. A variety of routine chemical and biological data on the lakes is being collected along with routine physical and climatic data in order to identify factors affecting the rate and severity of eutrophication.

Chemical and biological measurements during 1966 and early 1967 established the oligotrophic nature of Anderson-Cue Lake. In March, 1967, nutrient additions to the lake were begun. It was decided to add sufficient nitrogen to raise the total N content of the water 0.50 mg N/1 over a period of one year (assuming all nitrogen would stay in solution). This is equivalent to 500 mg/m^3-yr or about 10 mg/m^3-week. The volume of Anderson-Cue Lake was estimated to be 248,000 m^3. Thus a weekly loading of 2.48 kg N was desired. This was achieved by adding 21.2 lbs of ammonium chloride to 300 gallons of sewage effluent, which was trucked out to the lake site and fed from a holding tank into the lake with a chemical feed pump at a rate of 1.8 gal/hr. The nutrient outfall is located 2 ft below the surface and 200 ft off the south shore of the lake in about 10 ft of water.

It was decided to increase the total phosphorus content of the lake by 0.0427 mg P/1 in one year. This is equivalent to 42.7 mg/m^3-yr or 0.854 mg/m^3-week. For the lake a loading rate of 0.212 kg P/week is indicated. This was achieved by adding 2.47 lb of Na_3PO_4 to the sewage effluent each week.

Originally it was planned to add only sewage effluent to the experimental lake. This would have been feasible if Berry Pond (one acre surface, maximum depth, 13 ft) could have been used as originally planned, but its trophic characteristics obviated this plan. Nearly a million gallons of sewage effluent would have to be transported to Anderson-Cue Lake annually for the desired nutrient loading rate. Thus logistics precluded the use of sewage effluent alone, and it became necessary to enrich the effluent with nitrogen and phosphorous compounds.

After two years, the method of nutrient addition was changed to direct application of the chemicals to the lake by towing a burlap bag behind a motor boat. The towing pattern was simply to make a large circle in the middle of the lake. This method was considered an improvement since a residue was often found in the holding tank.

Nutrient Budgets for the Experimental and Other Lakes

The above nutrient addition rates compare closely with those estimated for the nutrient budget of Lake Mendota, Wisconsin, by Lee et al (1966). This eutrophic lake receives a heavy influx of nutrients from agricultural drainage, but ground water and atmospheric precipitation also make important contributions. The nitrogen loading of Lake

Mendota was estimated to be 556,000 lb per year, or 534 mg/m^3-yr. Of this quantity, Brezonik and Lee (1968) have estimated that two-thirds or 360,000 lb remain in the lake and is deposited in the sediments, while the remainder is lost through the outlet and by denitrification. The phosphorus budget for Lake Mendota was estimated to be 44,900 lb per year or 42.7 mg P/m^3-yr. Table III-1 summarizes the computed nutrient budget for Lake Mendota.

Relatively few other lake nutrient budgets have been established. Mortimer (1939) constructed a nitrogen balance for Lake Windermere (England). He found a close balance between input and output -- 326 and 318 metric tons, respectively. Hutchinson (1957) felt that nutrient inflow and outflow normally would balance closely in oligotrophic lakes, but not in eutrophic lakes. Rohlich and Lea (1949) reported an extensive nutrient balance on Lake Mendota, Wisconsin. Of the estimated 156 metric tons of nitrogen entering the lake annually, only 41 tons left through the surface outlet. Corresponding values for phosphate were phosphate were 16.4 and 11.6 metric tons. Partial nutrient budgets were determined for the lower Madison lakes by Sawyer et al (1945). However, only soluble phosphorus and inorganic nitrogen inputs were measured rather than total values, and the usefulness of the results is thus impaired. Aside from nutrient balances on Lake Tahoe (McGauhey et al, 1963) and Lake Washington (Edmondson, 1968) no other definitive nutrient budgets are known. Less detailed budgets have been drawn for a few other lakes--for example, Lake Fure in Denmark (Berg, 1958), Castle Lake in California (Goldman, 1961) and western Lake Erie (Curl, 1959). Various aspects of nitrogen and phosphorus budgets and sources have been treated by numerous workers. Brezonik (1968), Feth (1966), and Fruh (1967) have reviewed these studies in considerable detail.

Table III-2 lists the most common nutrient sources and sinks for lakes. Only some of these are applicable to the study lakes. Artificial enrichment represents the most significant nutrient source for Anderson-Cue Lake. The possible natural sources of nitrogen are biological fixation, atmospheric precipitation, air-borne particulates and surface and subsurface runoff. Preliminary results indicate the rainfall directly on the lake surface is the most important natural source. Nitrogen fixation has not yet been measured in the lake, but the near absence of blue-green algae in the biota of the lake implies that it does not occur. While bacterial fixation is possible, available carbon substrates are low and indicate the source is probably negligible. Contributions from runoff appear to be small. The amount of runoff draining into the lake is apparently low, and the soil is so nutrient depleted that rainfall runoff would pick up little or no additional nutrients in passing through and over the soil.

Measurements of the nutrient content of the rainfall were made periodically in 1967 and 1968. A summary of the results are shown in Table III-3. The nitrogen content of rainfall appears to be quite variable. However, these results can be combined with the rainfall amounts (see Section IV, Table IV-1) to yield an estimate of the total nitrogen contribution of rainfall to Anderson-Cue Lake. For 1968, 44 kg

Table III-1

ESTIMATED NUTRIENT BUDGET FOR LAKE MENDOTA, WISCONSIN[1, 2]

Source	Nitrogen Contribution kg.	Contribution %	Phosphorus Contribution kg.	Contribution %	Sink[4]	Nitrogen Lost kg.	Lost %
Municipal and industrial wastewater	21,200 (total)	8	7,750 (total)	36	Outlet loss	41,300	16.4
					Denitrification	28,000	11.1
Urban runoff	13,700 (soluble)	5	3,680 (soluble)	17	Fish catch	11,300	4.5
Rural runoff	23,500 (soluble)	9	9,100 (soluble)	42	Weed removal	3,250	1.3
Precipitation on lake surface	43,900	17	64 to 3,460	2			
Ground water	113,000	45	274	2	Ground water recharge		—
Nitrogen fixation	36,100	14	——	—	Sediments and other losses[5]	168,000	66.7
Marsh drainage		—		—			
Approx. Total	252,000	100	21,240[3]	100		252,000	100

[1] After Lee *et al.* (1966) and Brezonik and Lee (1968)

[2] The values presented are only rough approximations

[3] This total based on 455 kg. per year of phosphorus in precipitation on the lake surface

[4] Phosphorus sinks have not been determined but outlet loss and sediment deposition probably account for most of the phosphorus

[5] By difference between total sinks (assumed to equal total sources) and sum of all other calculated sinks. Other sinks are probably small, and sediment deposition accounts for most of the nitrogen in this category.

TABLE III-2

SOURCES AND SINKS FOR THE NUTRIENT BUDGET OF A LAKE

SOURCES

1. Air-borne
    - Rain water
    - Aerosols and dust
    - Leaves and miscellaneous debris

2. Surface
    - Agricultural runoff and drainage
    - Urban storm water runoff
    - Marsh drainage
    - Runoff and drainage from uncultivated land
    - Domestic waste effluents
    - Industrial waste effluents
    - Wastes from boating activities

3. Underground
    - Natural groundwater
    - Subsurface agricultural and urban drainage
    - Subsurface drainage from septic tanks near lake shore

4. *In situ*
    - Nitrogen fixation
    - Sediment leaching

SINKS

Effluent loss
Groundwater recharge
Fish caught or removed
Weed harvesting
Insect emergence
Evaporation (aerosol formation from surface foam)
Denitrification
Sediment deposition of detrital particles
Inorganic precipitation (for calcium phosphate, and some trace metals) and deposition into sediments

Table III-3

AMOUNT AND NUTRIENT CONTENT OF RAINFALL AT ANDERSON-CUE LAKE, 1968

Date	Amount[1] Inches	TON mg/1	NH_3-N mg/1	NO_3-N mg/1	o-PO_4 μg/1	t-PO_4 μg/1
2-19	1.00	—	0.46	0.40	230	—
2-26	0.25	—	0.23	0.94	20	—
3-4	0.35	—	0.80	0.26	25	—
3-11	1.20	0.57	0.86	0.24	18	—
4-15	0.65	0.67	0.33	0.27	2.2	—
5-6	0.45	0.64	0.10	0.30	28	—
5-13	0.75	0.33	0.0	0.15	20	—
5-27	3.35	0.11	0.02	0.05	—	—
6-24	6.65	0.24	0.02	0.14	9	30
7-5	4.00	0.39	0.05	0.09	10	30
7-25	4.65	0.01	0.01	0.08	8	—
8-2	0.85	0.50	—	0.29	—	20
8-19	2.10	0.34	0.14	0.22	33	70
9-3	10.85	0.07	—	0.09	—	20
9-16	4.30	0.07	0.11	0.16	5	—
10-11	2.85	0.12	0.05	0.11	12	—
10-19	3.70	0.11	0.21	0.04	4	—
11-11	3.60	0.23	0.07	0.05	25	30
12-9	2.25	0.54	0.18	0.11	18	—

[1] Total amount of rain in period from date on previous line to the date listed on the line. First line indicates rainfall from Jan. 1 to Feb. 19; last line indicates amount of rain from Nov. 12 to the end of the year.

TABLE III-4

PARTIAL NUTRIENT BUDGET FOR ANDERSON-CUE LAKE, 1968

NITROGEN

	kg	mg/l of lake water[1]
Sewage and nutrient mixture	124	0.67
Rainfall on lake surface	44	0.24
Total	168	0.91

Other possible nitrogen sources not completely evaluated are nitrogen fixation, groundwater seepage, subsurface runoff and air-borne particulates (leaves, etc.). Present information indicates all these except perhaps the last were insignificant in 1968.

PHOSPHORUS

	kg	mg/l of lake water
Sewage and nutrient mixture	10.60	0.057
Rainfall on lake surface	2.67	0.014
Total	13.27	0.071

Other possible phosphorus sources are groundwater, subsurface runoff and air-borne particulates. Present information indicates the first two were insignificant, but there is insufficient information to evaluate the last source.

[1] This is the concentration which would result if the amount of nutrient in column 1 were diluted to the volume of the lake (approximately 150 acre-feet or 185,000 m^3).

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nitrogen was added to the lake by rainfall directly on the lake surface. (This value corresponds with 49.4 kg nitrogen added to the lake by rainfall during 1967, as previously computed by Brezonik and Putnam, 1968). By comparison, about 124 kg N was added by the nutrient mixture. Actually a greater disparity between these two sources exists than is indicated by the magnitude of the two numbers. The rainfall contribution is diluted in a large volume of water, whereas the nutrient mixture is highly concentrated and contributes an insignificant amount of water to the lake. Phosphate analyses from 1968 indicate a wide range of phosphate in rain water. The data indicate that about 2.7 kg P was contributed by rainfall in 1968. This compares with 10.6 kg added to the lake in the nutrient mixture. These results are summarized as a nutrient budget for Anderson-Cue Lake in Table III-4.

Sampling Program

The duration and frequency of the sampling program is detailed in Section V (Chemical Studies) and Section VI (Biology). The tests conducted and the methods utilized are displayed in Appendix A and B.

Generally, background data collection began in January, 1966 on a bi-monthly basis. Nutrient addition was initiated in March, 1967. Bi-monthly sampling was conducted through January, 1970.

Several special investigations were conducted in conjunction with these regular investigations. The special studies included the weekly collection of samples for zooplankton analyses from January, 1967 until December, 1968. This study correlated population dynamics with productivity. A subsequent bi-weekly research program dealt with the interactions of zooplankton and their fish predators. This research continued from June, 1968 through April, 1970.

An intensive program was undertaken to develop a quantitative trophic state index using multivariate statistical techniques. The sampling schedule used in this study was designed to provide information on the average chemical, biological and physical characteristics of fifty-five central Florida lakes over a one year period.

Systematic sampling of the fifty-five lakes commenced in June, 1969. It was decided to sample all fifty-five lakes at four-month intervals for a period of one year. Hence, the subsequent fifty-five lake sampling periods were in October, 1969, February, 1970 and June, 1970. From the fifty-five lake experimental group a sub-group of nineteen lakes was selected. These lakes were sampled at two-month intervals so that in addition to being sampled with the main group they were sampled in August, 1969, December, 1969 and April, 1970. The nineteen lakes were selected on the basis of being representative of several trophic types of lakes and/or being of special interest. It was felt that this sub-group of lakes could be used to reflect seasonal trends in lake characteristics without sampling the entire fifty-five lakes on a closer time interval.

SECTION IV

PHYSICAL CHARACTERISTICS OF THE RESEARCH LAKES AND DRAINAGE BASINS

General

Anderson-Cue and McCloud Lakes (see Figure IV-1) are located in a region of high sand hills with many circular to elliptical basins which have resulted from solution of the underlying limestone. Both lakes have small drainage basins with no influent or effluent streams.

The tops of many of the surrounding hills reach elevations of 190 to 220 ft, MSL. Westward at Melrose the terrain changes from sand hills to the Okefeenokee Terrace, a poorly drained terrace 140 to 160 ft, MSL. Eastward, beyond Baywood, the sand hills are bound by lower marine terraces. The immediate area of the research lakes is the Trail Ridge portion of the Central Highlands.

Three hydrographic surveys of Anderson-Cue Lake have been made since the fall of 1965. Echo soundings were made in November, 1965; a stadia survey (including topography of the basin) was made in July-August, 1967; and echo soundings were again made in March, 1968. Using these data a topographic map of the lake and surrounding area was prepared and is shown in Figure IV-2. The highest level shown on the map was the shoreline which stood at 125.78 ft, MSL, in March, 1966, at which time the lake had a surface area of 19.3 acres and a volume of approximately 201 acre-feet. When it was decided to use McCloud Lake instead of Berry Pond as the control body of water in late 1966 the volume of water in McCloud Lake exceeded that in Anderson-Cue Lake by approximately 15 percent. This information was obtained by stadia survey.

Yearly excess precipitation over evaporation (30 year record) is 12 to 18 in. in the xeric hills surrounding Anderson-Cue Lake. (These data are not applicable to the research lake itself.) The excess precipitation and runoff percolate downward through breaks in the sands and clays of an aquifuge that overlies the Floridan aquifer. The influent drainage has resulted in a subsidence karst landscape which forms a principal recharge area in North Florida for the Floridan artesian system. Analyses of the water level data for Anderson-Cue Lake, the surrounding water table data, and the rainfall and evaporation records indicate that there is very little contribution from surface and subsurface runoff to the lake. Sands covering the basin are porous. Downward seepage rates are high and surface runoff is exceedingly low.

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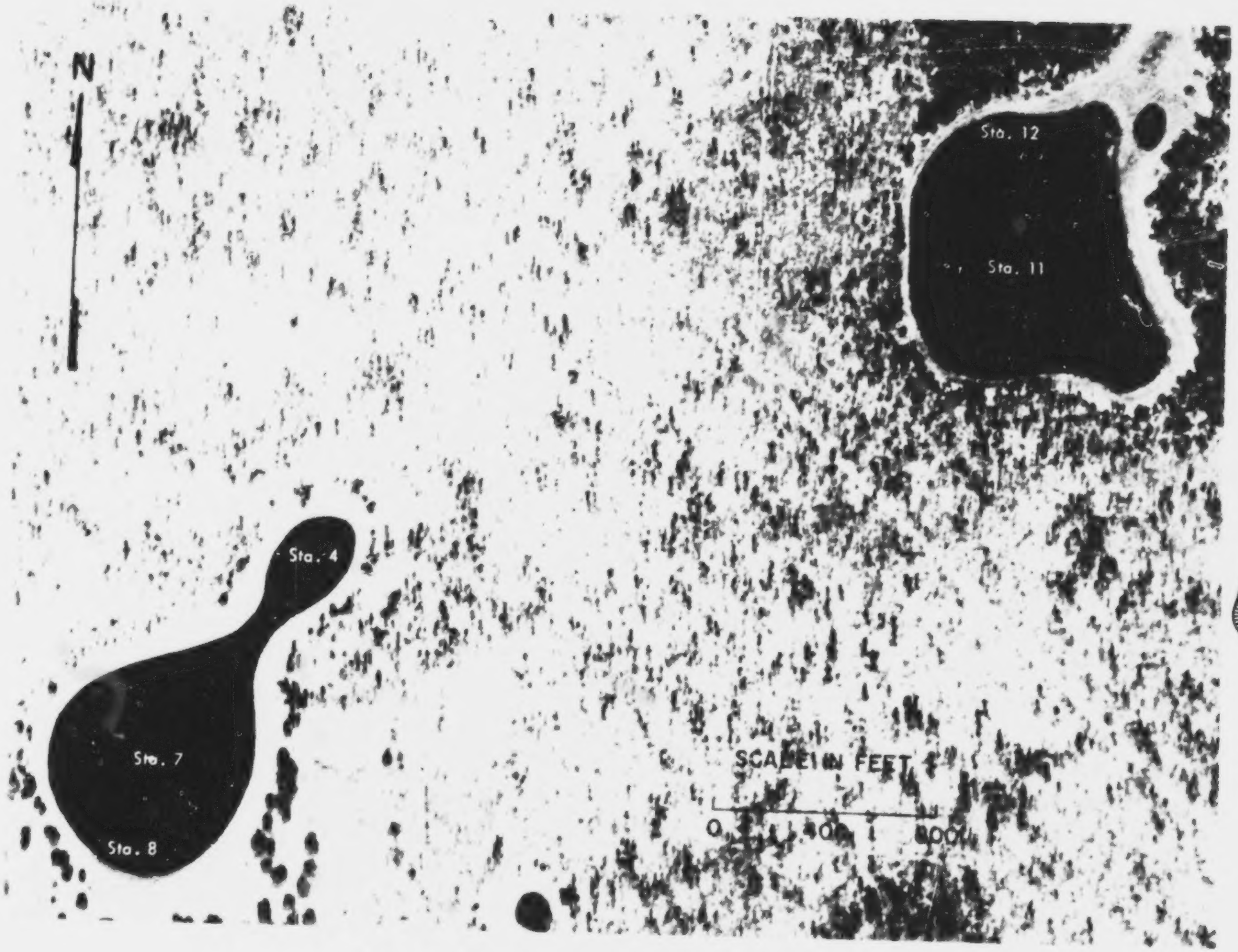
N
Sta. 12
Sta. 11
Sta. 4
Sta. 7
Sta. 8
SCALE IN FEET
0
400
800

Figure IV-1. Location Map of Anderson-Cue and McCloud Lakes.

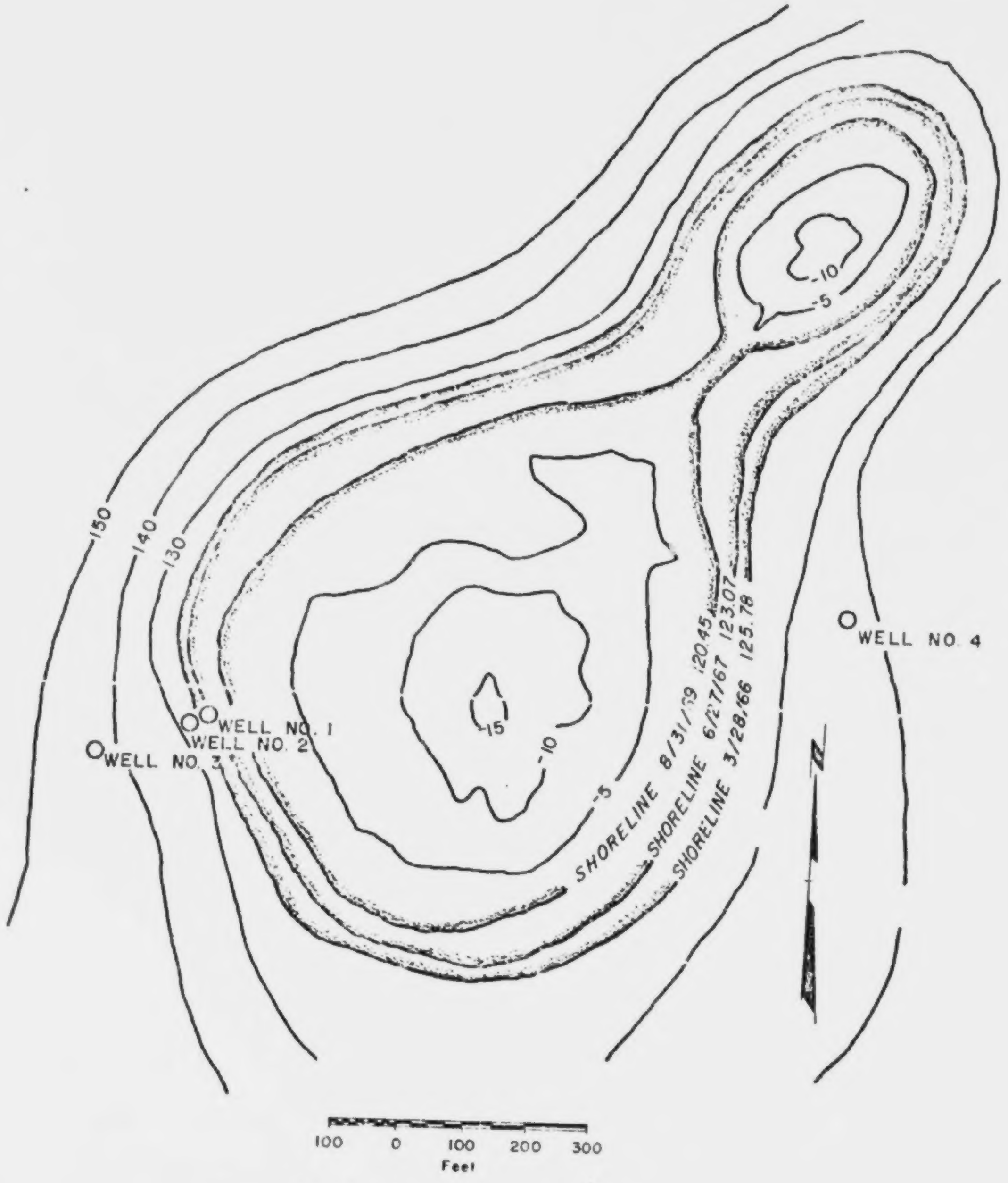
150
140
130
-10
-5
-15
-10
-5
WELL NO. 1
WELL NO. 2
WELL NO. 3
WELL NO. 4
SHORELINE 8/31/69 120.45
SHORELINE 6/27/67 123.07
SHORELINE 3/28/66 125.78
N
100
0
100
200
300
Feet

Figure IV-2. Topography of Anderson-Cue Lake.

Geology

Materials exposed in the sand hills are largely of two types: very fine surface sands and the underlying kaolinic gravels, sands and sandy clays. These sediments are known as the Citronelle Formation. Well borings show an aquifuge of from 80 to 100 ft of phosphatic sands, sandy clays and clays lying below the surface. These materials are known as the Hawthorne Formation of Lower and Middle Miocene Age. Underlying the Hawthorne Formation is the Floridan aquifer, the upper portion of which is the Ocala Limestone of Eocene Age.

The piezometric surface of the water in the Floridan aquifer is approximately 90 ft above MSL in the vicinity of Anderson-Cue Lake. The porous sand and gravel of the Citronelle Formation contain a perched water table above the aquifuge--the Hawthorne Formation. Anderson-Cue Lake is itself a perched lake. The lake level is the result of a balance between precipitation, evaporation and outflow into the water table aquifer and Floridan aquifer.

The vegetation in both lake basins is sparse and primarily scrub oak, indicative of poor nutrient conditions. There is no human habitation in either basin. The major source of nutrients for the lakes in their natural states appears to be from the atmosphere via precipitation and air-borne particulates.

Instrumentation

A Gurley water level recorder with staff gage and a recording rain gage were installed at Anderson-Cue Lake in February, 1966.

In September, 1967, an Aerovane wind recorder and Foxboro hygrothermograph were installed. The transmitter for the wind recorder was mounted on a pole approximately 150 ft from the south shore of the lake and three feet above the water surface. Examples of some of the instrumentation are shown in Figure IV-3.

Meteorological and Hydrological phenomena

Anderson-Cue Lake lies in a shallow valley oriented in a NNE to SSW direction and is surrounded by scrub oak and pine trees. These characteristics have a marked effect on the air-flow over the water surface. The air speed in general is calm to light (0-7 mph). The prevailing winds are from 30 to 60 degrees (NNE to NE) and from 210 to 240 degrees (SSW to SW). When a tropical storm or frontal system passes over or close to NE Florida the wind direction is influenced by such phenomena and higher wind speeds are recorded. A wind rose for the period October, 1967 to September, 1968, is shown in Figure IV-4.

View of Anderson-Cue Lake
Looking Northwest

Checking Rain Gage at Lake Site

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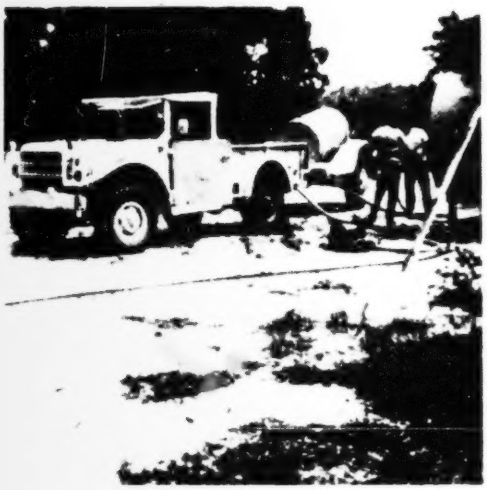
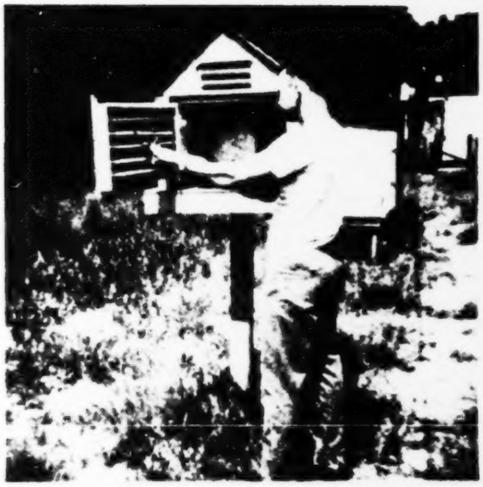


Unloading Sewage Effluent
into Storage Tank



Checking Hygrothermograph
at Lake Site

Figure IV-3.

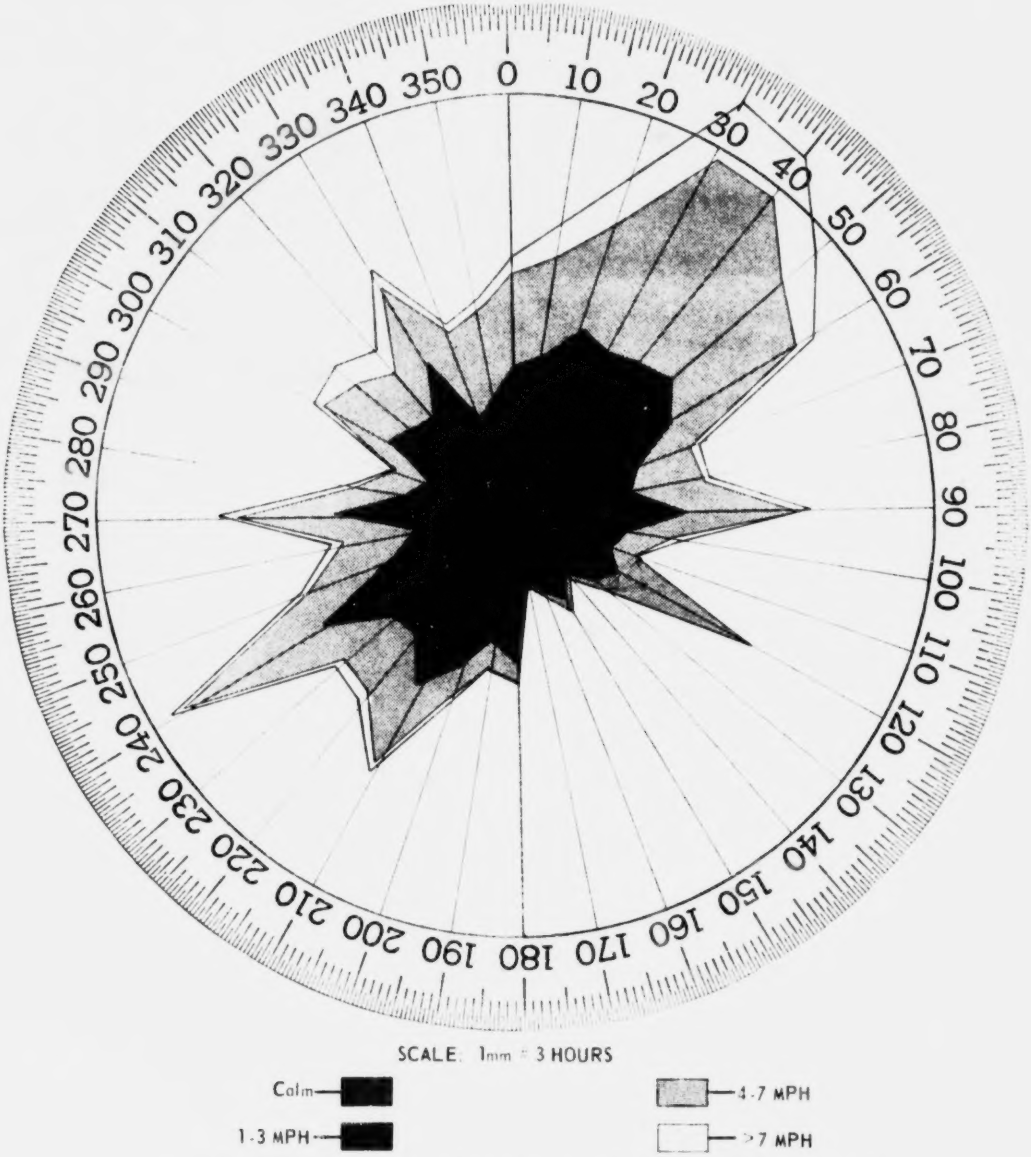


Figure IV-4. Wind Rose, Anderson-Cue Lake, October 1967 - September 1968.

The only significant currents in shallow Anderson-Cue Lake are wind currents. In bodies of water larger than Anderson-Cue Lake such surface water currents flow to the right of the wind and set up a clockwise circulation. In Anderson-Cue Lake, however, these currents cause a pileup of water on the leeward shore which is returned by fanouts in both clockwise and counterclockwise directions.

Many factors must be considered in attempting to explain the fluctuations of the lake level and the water table in the research area. These include evaporation, precipitation, and flow to the water table aquifer and Floridan aquifer. The most complex of these factors is evaporation. The question arises as to what percent of time in a certain period was the variation of dewpoint temperature with height such as to lead to condensation on or evaporation from the lake surface. An inversion of the dewpoint will develop if the surface acts as a heat sink to remove water vapor. This condition can be expected during clear nights when there is strong radiation from the ground; during times of high relative humidity; and during times of build-up of surface inversions which occur frequently in the Anderson-Cue Lake area. In fact, about 50 percent of the time the water vapor flux is directed downward. This reversal of evaporation is evident during non-daylight hours when winds are persistently less than 7 mph and relative humidity greater than 90 percent.

It is interesting to note from the rain gage records of the past year that during the periods when the vapor flux is directed upward (generally from 0800 hr to 1800 hr) approximately 0.12 to 0.15 of an inch of water is evaporated daily. This indicates the large amount of evaporation from the lake surface that can be expected unless the amount of precipitation plus condensation received when the lake acts as a heat sink can overcome the evaporation losses and losses to the water-table aquifer and Floridan aquifer.

Water in the water-table aquifer is unconfined so that its surface is free to rise and fall with the variance in rainfall. Rainfall on the Anderson-Cue Lake basin for the period March 28, 1966, through June 30, 1968, was deficient by 13.85 in. (the closest "departure from normal" data are accumulated at Gainesville, approximately 20 miles to the west). For the period November 2, 1967 through June 30, 1968 the deficiency was 8.56 in. This is shown in Figure IV-5 (refer to Figure IV-2 for location of test wells). Because the piezometric surface of the Floridan aquifer is below the level of the lake, water cannot move from the Floridan aquifer to the lake. The net groundwater flow during the period of study has been composed only of outflow to the water-table aquifer and to the Floridan aquifer, the greater flow being to the water-table aquifer east of the lake. Note the level of Well No. 4 in Figure IV-5.

As shown in Table IV-1, for the period March 28, 1966 through November 30, 1968, evaporation losses exceeded rainfall by 8.35 in. and approximately 65 acre feet of lake water was lost to the aquifers.

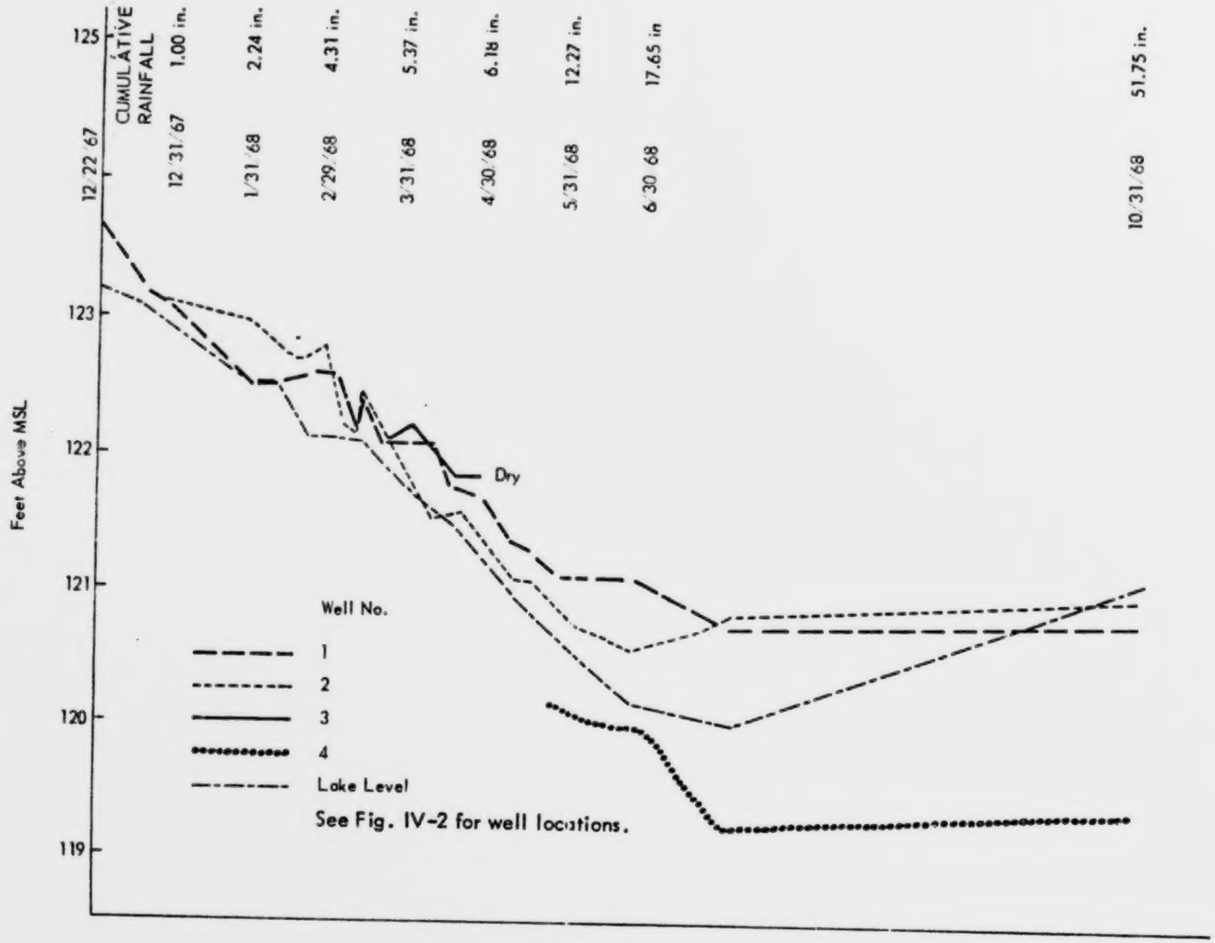


Figure IV-5. Ground and Surface Water Levels -- Anderson-Cue Lake.

TABLE IV-1
ANDERSON-CUE LAKE HYDROLOGICAL DATA

Dates	(1) Lake Evaporation (in.)	(2) Rainfall (in.)	(3) Lake Level (ft-MSL)
3/28/66			125.78
4/26/66	4.73	1.42	125.33
5/25/66	4.89	3.99	125.04
6/22/66	6.04	5.96	124.69
7/21/66	6.48	2.45	124.25
8/18/66	6.25	8.70	124.43
9/13/66	4.84	5.00	124.41
10/11/66	3.87	5.45	124.51
11/08/66	3.17	1.56	124.21
12/06/66	2.53	0.05	123.75
1/03/67	2.12	2.67	123.61
3/28/67	9.53	9.15	123.61
5/02/67	7.18	1.65	122.99
5/31/67	7.58	7.92	122.83
6/27/67	5.35	7.66	123.07
8/01/67	6.24	8.12	123.33
9/06/67	5.77	10.91	123.81
10/03/67	5.24	1.38	123.66
11/02/67	4.19	1.32	123.46
12/03/67	3.11	0.00	122.99
1/04/68	2.37	5.60	123.07
1/31/68	2.10	0.24	122.63
2/29/68	2.59	1.35	122.17
3/31/68	4.14	1.42	121.59
4/30/68	6.63	0.45	120.83
5/31/68	6.95	6.09	120.49
6/30/68	6.09	5.38	120.02
7/30/68	5.89	9.55	119.54
8/31/68	4.82	12.90	120.45
9/30/68	5.07	5.15	120.75
10/31/68	3.62	6.50	121.09
11/30/68	2.41	3.45	121.19
12/30/68	2.85	2.05	121.09
1/31/69	2.05	1.10	120.87
2/28/69	1.99	4.20	120.89
3/31/69	3.42	6.15	120.67 (est)
4/30/69	5.99	0.25	120.45
5/31/69	5.83	6.05	120.49
6/30/69	6.66	1.30	120.01
7/31/69	6.15 (est)	7.15	120.87
	186.73	171.69	-(55.40 in.)

Summary:		
186.73 (1)	55.40 (3)	
-171.69 (2)	-15.04	
15.04 in.	40.36	in. or approximately 56 acre/ft.

NOTE: Lake evaporation is computed from data collected at the U.S. Weather Bureau evaporation station at Gainesville, Florida. Pan coefficients are those used for Lake Okeechobee, Florida: Kohler, M.A., 1954, Lake and Pan Evaporation in Water Loss Investigations-Lake Hefner Studies, Technical Report: U.S. Geological Survey Prof. Paper 269, p. 128.

For this period, the residence time of water in Anderson-Cue Lake has been calculated to be 5.43 years. The same calculation holds true for McCloud Lake (control) which rises and falls at the same time and in the same proportion as Anderson-Cue Lake.

SECTION V

CHEMICAL STUDIES

Introduction

Trophic state is manifested by a variety of chemical and biological parameters. This section will summarize the routine chemical data obtained on the two study lakes; biological results will be presented in the following section. Results for Anderson-Cue Lake extend for a period of four years-from 1966 to the present. McCloud Lake has been sampled routinely since the beginning of 1967. During 1966 and 1967 sampling was approximately bi-weekly, especially for the important nutrient parameters. Sampling has been on a monthly basis since January, 1968, because short term variations have been found to be rather small. Monthly sampling has also allowed more time for other special studies. The objective of routine sampling is to define changes in the chemical and biological composition of the lake as it undergoes controlled eutrophication. To accomplish this requires a representative sampling program with careful attention to possible temporal, lateral and depth variations in composition.

Three permanent sampling stations were located in Anderson-Cue Lake. Stations 4 and 7 are in the centers of the lake's two basins, and Station 8 is on the south shore in about 3 feet of water. The location of these stations is shown in Figure IV-1. Two permanent stations are located in McCloud Lake, Station 11 near the center of the lake, and Station 12 near the north shore in 3 feet of water. Samples were taken at three depths (top, middle and bottom) at Stations 4, 7 and 11, and at mid-depth at the shore stations (8 and 12). For more detailed determinations of lateral variability, a sampling grid of about 50 stations was established on Anderson-Cue Lake; these are indicated in the isopleth maps shown in later discussions of these studies. Parameters measured routinely (bi-weekly or monthly) include dissolved oxygen, pH, conductivity, acidity, dissolved and suspended solids, ortho and total phosphate, total and particulate organic nitrogen, ammonia, nitrite, and nitrate. In addition, data have been routinely collected on physical conditions such as water temperature and Secchi disc transparency. Other major and minor chemical constituents have been determined less frequently. These include chloride, sulfate, calcium, magnesium, sodium, potassium, silica, iron, manganese, chemical oxygen demand and biochemical oxygen demand. Chemical characterization of lake sediments has included determination of percent volatile solids, total organic nitrogen, ammonia, total phosphate, iron, and manganese (see Appendix A for methods).

Chemical Characteristics

The two lakes are typical of the small lakes in the Trail Ridge portion of the Central Highlands of Florida. Table V-1 summarizes the chemical characteristics of the lakes. Few significant changes in gross chemical composition have been noted during the period of record; hence the values in Table V-1 are mean values for each lake during the period of record. Both lakes are colorless, low in dissolved solids and extremely soft. The waters are acidic, with typical pH values ranging between 4.6 and 5.5. The waters have little buffer capacity and essentially no alkalinity. Consequently, acidity titrations have been used to estimate total CO_2. Specific conductance has increased in Anderson-Cue Lake from about 25 µmho cm^{-1} to about 40 µmho cm^{-1} over the last two years. Corresponding increases in McCloud Lake have been less- from 30 to 35 µmho cm^{-1}. Some of the increase would seem to be the result of excess evaporation over precipitation during the period; nutrient additions were probably responsible in part for the increase in the experimental lake.

The low dissolved solids and ionic content of the lakes are indicative of the waters' origin, i.e. atmospheric precipitation. Table V-1 lists some comparative values for the chemical composition of rain water at the lake site. Concentrations of major ions compare reasonably close for the lakes and rain water. The ionic content of rain water varies considerably, but the values in Table V-1 represent approximate ranges for the various ions. The data are too sparse for reliable estimates of mean rainfall composition, which would be useful in deriving a chemical model for the lake waters from rainfall composition and possible chemical interactions between rain water runoff and soil constituents. The primary reason for studying the composition of rain is to determine its significance as a nutrient source. The rainfall values for nitrogen and phosphorus species in Table V-1 are mean values revealing the importance of rain as a nutrient source, especially for lakes unaffected by cultural sources.

While concentrations of major ions are not likely to limit primary production in either lake, the paucity of several is likely to select against certain types of organisms. Low silica probably is a contributor to the small diatom populations; low calcium and magnesium indicate the waters are unsuitable for macrophytes like Chara and some algae which prefer hard water. The low pH of these lakes is undoubtedly a contributing factor for the low populations of blue-green algae, but encourages the maintenance of a desmid population. The relatively low nutrient levels favor organisms like Dinobryon and Synura, which prefer such environments (Hutchinson, 1967).

TABLE V-1

CHEMICAL COMPOSITION OF ANDERSON-CUE AND McCLOUD LAKES AND RAIN WATER

Constituent[1]	Anderson-Cue Lake[2]	McCloud Lake[2]	Rain Water[3]
Specific conduct.	31.65	32.29	10-30
pH	4.93	4.85	5.3-6.8
Acidity as $CaCO_3$	3.20	3.50	
Cl^-	6.25	5.93	1.74
$SO_4^=$	5.4	5.0	0.8
Na^+	2.49	2.81	0.29-1.85
K^+	0.51	0.25	0.13-0.21
Ca^{+2}	0.74	0.61	1.01-2.06
Mg^{+2}	0.58	0.57	0.06-0.35
Silica	0.14	0.10	
Total org. N	0.47	0.42	0.32
Particulate org. N	0.26	0.21	
NH_3-N	0.234	0.105	0.208
NO_2^--N	0.0014	0.0012	0.005
NO_3^--N	0.067	0.041	0.209
Ortho phosphate	0.0084	0.006	0.027
Total phosphate	0.017	0.012	0.033
COD	10.7	10.7	
BOD	1.02	0.86	
Sus. solids	5.9	5.2	
Turbidity	11.1	8.8	

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[1] All values in mg/l except specific conductance (μmho con^{-1}) and pH. Nitrogen species are in mg N/l and phosphate in mg P/l.

[2] Mean values for all samples from the mid-lake stations during 1967 and 1968.

[3] Nutrient (and Chloride) concentrations are mean values for all determinations in 1968; other values represent range encountered in one to four determinations during 1967-68.

TABLE V-2

TEMPERATURE AND DISSOLVED OXYGEN: ANNUAL AVERAGES AT THREE DEPTHS IN STATIONS, 4, 7, 11

Station &		Temperature[1]			Dissolved Oxygen[2]		
Depth		1967	1968	1969	1967	1968	1969
4	Top	23.61	22.11	23.05	7.39	7.94	9.08
	Mid	23.06	21.74	22.55	7.39	7.96	8.05
	Bottom	22.91	21.57	22.66	7.27	7.48	8.20
7	Top	23.42	22.13	23.09	7.66	8.04	8.48
	Mid	23.13	21.83	22.71	7.56	8.03	8.34
	Bottom	22.90	21.08	22.43	7.37	7.30	8.18
11	Top	23.49	22.65	23.28	7.58	8.07	8.35
	Mid	22.78	21.98	22.49	7.50	8.02	8.25
	Bottom	21.93	21.73	22.04	6.26	6.90	7.28

[1] Temperature in °C

[2] Dissolved Oxygen in mg/l

Temperature and Dissolved Oxygen

Neither lake shows much evidence for stable thermal stratification at any time of the year. Table V-2 summarizes average temperature and dissolved oxygen at the three depths sampled for Stations 4, 7, and 11. The maximum difference in average annual temperature from top to bottom was about 1.5° C for Station 11 in 1967; differences at the other stations have been 1°C or less. Somewhat larger differences at Station 11 have been found from top to bottom on particular days. During the period of high water in summer of 1967, 3°C differentials were sometimes found, but the changes occurred in the bottom few feet, and most of the lake was freely circulating. Temperature profiles in Anderson-Cue Lake are normally within one degree Celsius from top to bottom. During periods of intense warming and calm weather, temporary stratification could occur in either lake, but we have not yet found such conditions in over three years of sampling. Water temperatures range from about 12°C in winter to about 32°C in mid-summer.

Dissolved oxygen profiles also show little change with depth. Average differences at Stations 4 and 7 in 1967 were only 0.12 and 0.29 mg/l, respectively. Slightly greater differences occurred in 1969; 0.75 and 0.95 mg/l at Stations 4 and 7, respectively; these may reflect the somewhat greater production and standing crop in Anderson-Cue in 1969. Vertical differences at Station 11 were greater (1.2 - 1.3 mg/l) than the Anderson-Cue results for the three years, corroborating the greater vertical stability of this lake. There is no evidence of oxygen depletion in the bottom water of either lake at any time, but considering the lack of thermal stratification and oligotrophic conditions, this is not surprising. Seasonal variations in dissolved oxygen largely reflect changes in solubility with temperature. Figures V-1 and V-2 show the average temperature and dissolved oxygen values for 1967, 1968, and 1969 at Stations 7 and 11, respectively. Oxygen values generally were near saturation, but a tendency toward slight undersaturation is noted. Rates of photosynthesis and respiration in either lake are too slow to markedly influence dissolved oxygen, but this should change in Anderson-Cue Lake as nutrient additions are continued.

Variations in Biogenic Compounds

In routine chemical analyses, greatest attention has been centered on nitrogen and phosphorus compounds, which presumably are most critical for primary production, and on other substances whose concentrations are affected by the activity of organisms. Both lakes were extremely poor in nutrients before enrichment began. Ammonia ranged between 0.02 and 0.06 mg N/1; nitrate was less than 0.04 mg N/1, and total organic nitrogen averaged about 0.3 mg N/1. Ortho-phosphate was often undetectable and averaged less than 5 µg P/1. Total phosphate exhibited similarly low concentrations. The above concentration ranges are for 1966 and early 1967, before nutrient enrichment of Anderson-Cue Lake. Enrichment began in March of 1967 and is still continuing. Figures V-3 to V-7 show the seasonal variations in nitrogen and phosphorus forms in the two lakes from January, 1967 to December, 1969. The points on each plot represent mean values for the mid-lake stations in each lake. Differences between the two lakes may have been somewhat greater than the plots indicate. Occasional high nutrient concentrations were encountered in the bottom sample of McCloud Lake; these may have resulted from stirring the sediment during sample collection. These are included in the averages, but are probably not representative of the lake as a whole.

Seasonal patterns in both lakes are rather similar. With the exception of total organic nitrogen (Figure V-3), nutrient concentrations are consistently higher in Anderson-Cue compared to McCloud Lake. Total organic nitrogen does not appear to exhibit a marked seasonality in either lake. The high and erratic nature of the data in mid-1967 is partially the result of analytical difficulties subsequently corrected. Concentrations were usually slightly higher in the experimental lake during 1968 and 1969.

The effect of enrichment on ammonia concentrations is clearly illustrated in Figure V-4. Ammonia has been consistently higher in the experimental lake throughout 1967, 1968, and 1969, but differences became much more pronounced during 1968. There does not seem to be a major seasonal influence on ammonia; rather concentrations fluctuate considerably from month to month. It is interesting to note that the

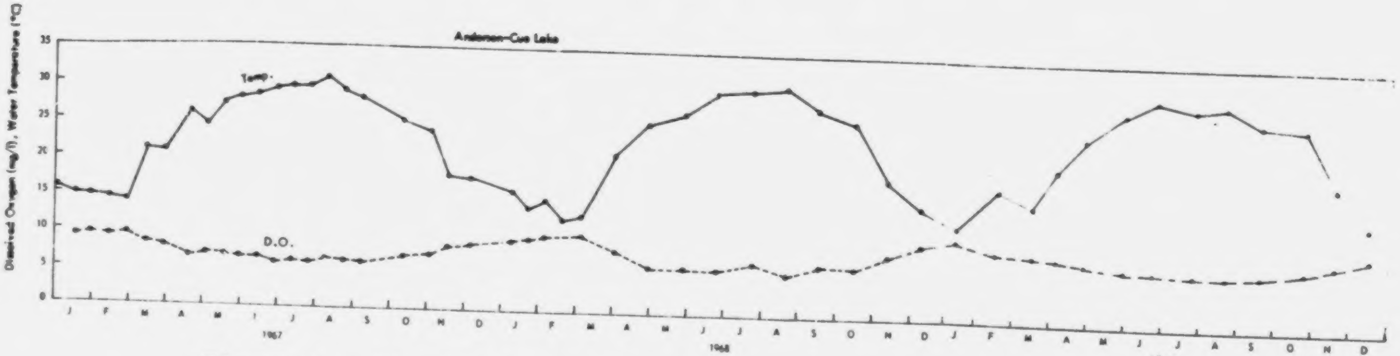


Figure V-1. Dissolved Oxygen and Water Temperature in Anderson-Cue Lake

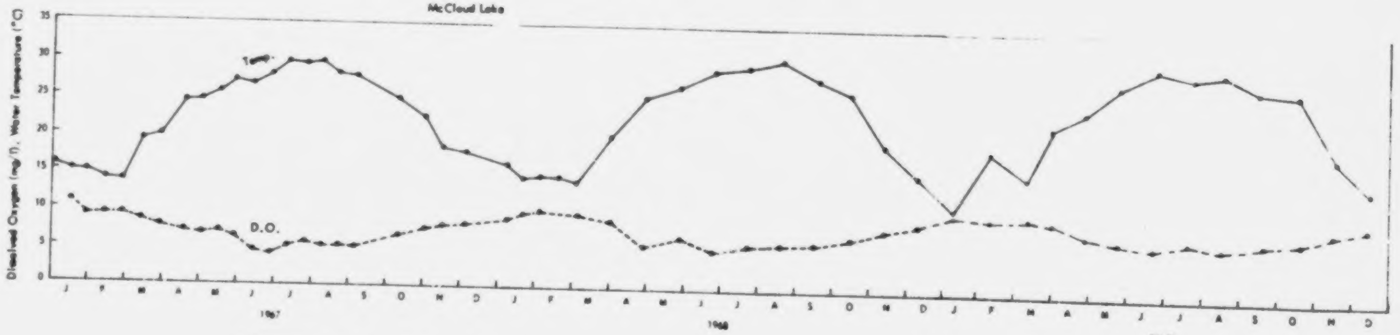


Figure V-2. Dissolved Oxygen and Water Temperature in McCloud Lake

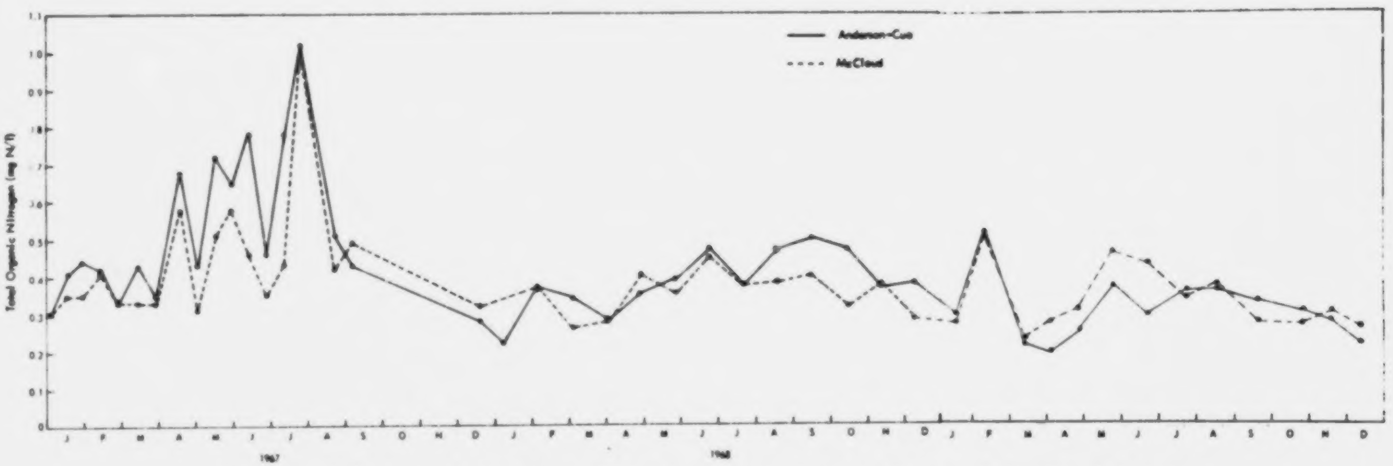


Figure V-3. Total Organic Nitrogen in Anderson-Cue and McCloud Lakes

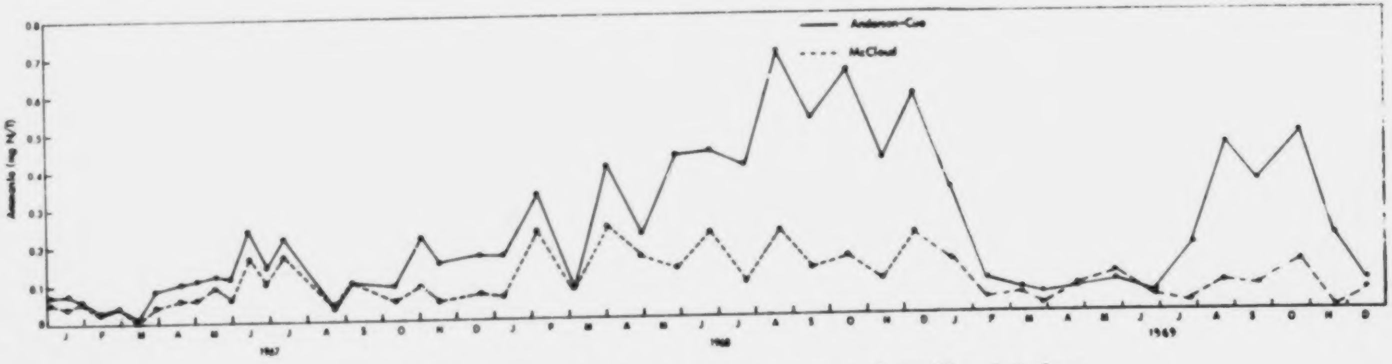


Figure V-4. Ammonia in Anderson-Cue and McCloud Lakes

biological forces within the lake can exert an over-riding influence on the general trend toward increased concentrations resulting from nutrient input. A decrease from about 0.34 mg NH_3-N/l to 0.06 mg NH_3-N/l occurred in Anderson-Cue Lake during February, 1968. This corresponded to a winter bloom of Dinobryon and Synura. After the bloom, ammonia increased to 0.40 mg N/l within the next month. A similar but smaller decrease and subsequent increase occurred contemporaneously in McCloud Lake. Ammonia was being continuously fed into the experimental lake at a rate equivalent to a 0.1 mg N/l average increase in the water for the two month period (February and March). With some fluctuations ammonia continued to increase in Anderson-Cue Lake during 1968 while values in McCloud Lake showed a much smaller trend. Ammonia in Anderson-Cue Lake has now increased to levels commonly considered indicative of eutrophy.

Nitrate seasonal patterns (Figure V-5) are nearly identical for the two lakes, but the experimental lake has consistently higher values (by about 0.01 to 0.09 mg NO_3-N/l). The peak concentrations for both lakes in 1968 occurred in early February; minimum values were found in late May. The seasonal pattern probably can be explained by uptake of nitrate during the late winter bloom and inhibition of nitrification at warm summer temperatures. Nitrate concentrations have been below 0.10 mg N/l except during the winter of 1968. No winter maximum was found in 1967. In 1969, peak concentrations occurred in early March and minimum values occurred in June and July for both lakes.

Ortho-phosphate concentrations in both lakes (Figures V-6) are normally quite low and follow a similar seasonal pattern. Peak concentrations occur from late spring to mid-summer. Values were below 10 μg P/l in both lakes during winter and early spring and again in fall of all three years. The low phosphate values (except during summer) indicate phosphorus is probably the limiting eutrophying factor in Anderson-Cue Lake. The seasonal pattern of ortho-phosphate is rather the opposite of that found in north temperate lakes and is somewhat unexpected. This pattern (summer maximum) has been found for ammonia in some Polish lakes (Karcher, 1939). Data on seasonal variations of phosphate in other unstratified lakes are rather sketchy. There seems to be a consistent trend in the total phosphate of both lakes to higher values in summer and minimum values in early winter. With few exceptions concentrations were higher in the experimental lake than in the control, but the differences were usually not striking. Concentrations increased greatly in both lakes in early fall of 1968 and reached maximum values of 93 and 84 μg P/l (average concentrations) in Anderson-Cue and McCloud respectively, in mid-October. Data for this period in 1967 are not available for comparison. In August, 1969, total phosphate concentrations reached maximum values of 31 and 23 μg P/l (average concentrations) for Anderson-Cue and McCloud respectively. Such a rapid and large increase in total phosphate and subsequent rapid decline would seem to imply an important role for the sediments as a phosphorus source and sink since they alone would seem capable of providing such amounts to the water.

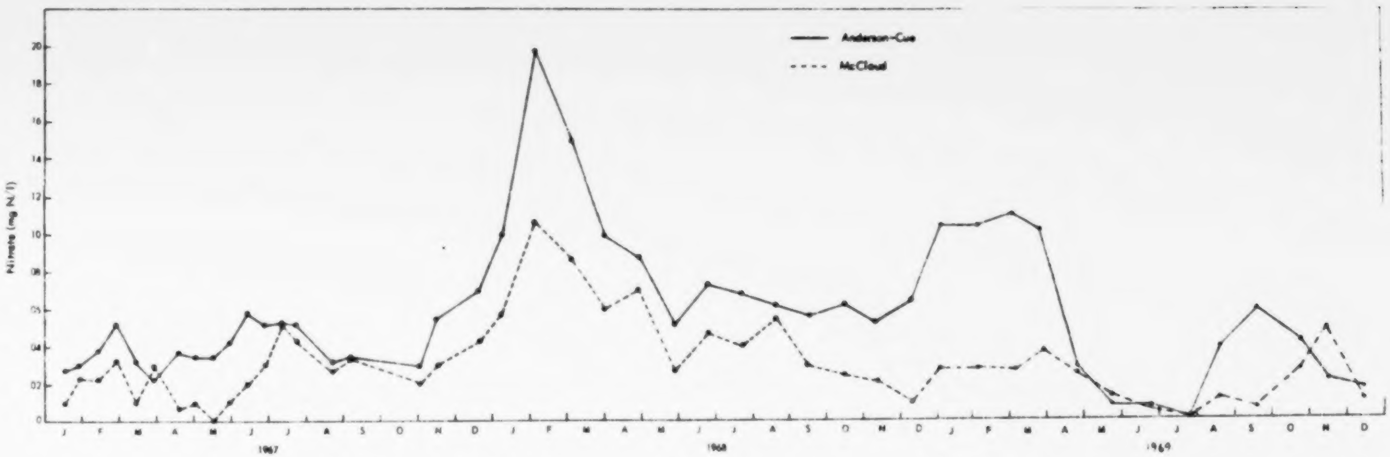


Figure V-5. Nitrate in Anderson-Cue and McCloud Lakes

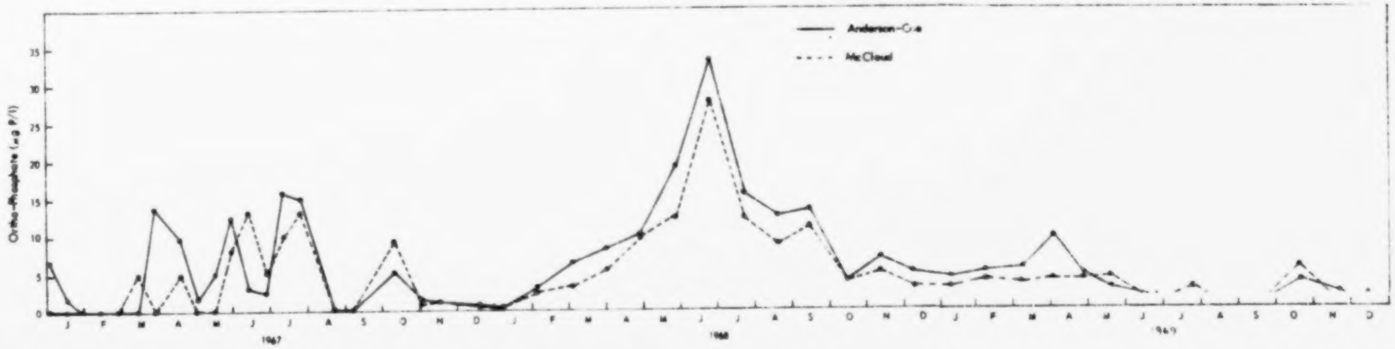


Figure V-6. Ortho-Phosphate in Anderson-Cue and McCloud Lakes

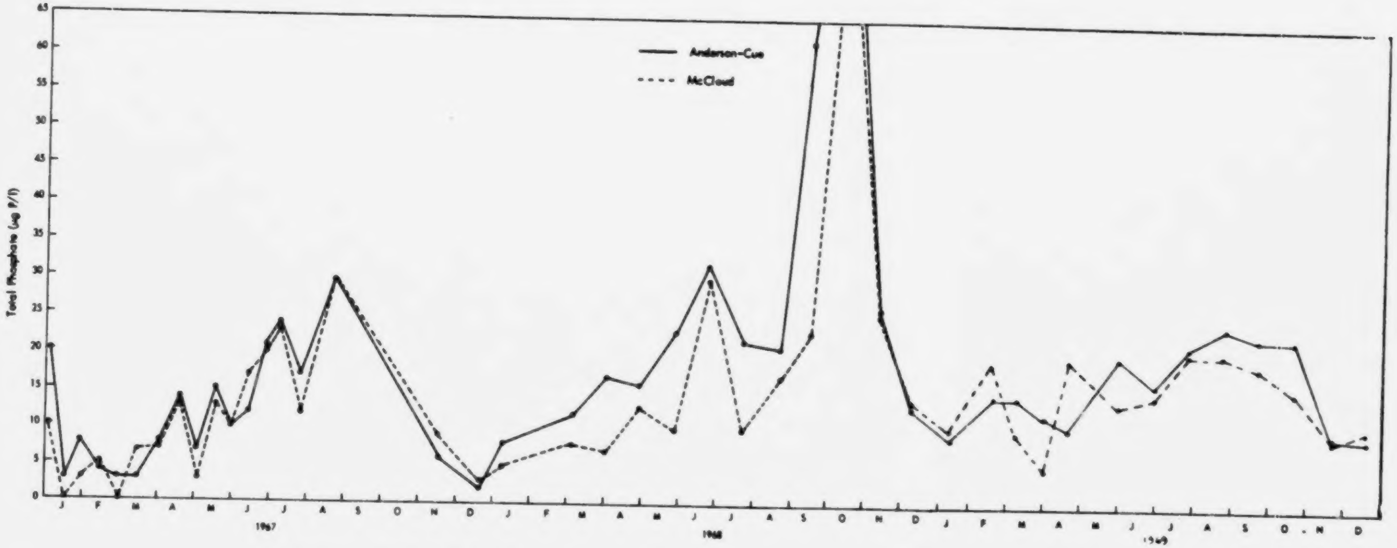


Figure V-7. Total Phosphate in Anderson-Cue and McCloud Lakes

During the first 21 months of nutrient enrichment (through December, 1968), approximately 217 kg nitrogen and 18.5 kg phosphorus, mostly as ammonia and ortho-phosphates, were added to Anderson-Cue Lake through the nutrient outfall. This was sufficient to increase the N and P levels in the lake by 0.87 and 0.082 mg/l, respectively, at the lake's volume in 1967, if all the nutrient material remained in the lake. The actual nutrient increase should have been larger because of the decrease in lake volume in 1968. Inspection of Figures V-3 to V-7 shows this theoretical situation clearly does not apply. Increases in total N and P concentrations do not approach these levels and much of the added nutrient evidently was deposited in the sediments or was lost through ground water seepage. This has been found to be the case in other lakes where nutrient budgets have been constricted. This would seem to imply an important role for sediment regeneration of nutrients in the eutrophication process. Possibly the onset of deleterious conditions in the eutrophication process is contingent upon exhaustion of the sediment's capacity to retain nutrients.

Considerably greater detail is known about the variations of chemical species in the lakes than was presented above. The data in Figures V-1 to V-7 represent mean values for each lake on a particular date. Data were collected from the three depths at each mid-lake station on each date. Table V-3 summarizes results for some biogenic elements at the three depths; the data indicate the lakes are well mixed vertically (as implied by the temperature and dissolved oxygen data in an earlier section), and the vertical differences in chemical species were usually very small. Differences between the stations in each lake are also small for most chemical species. Occasionally, parameters such as total organic nitrogen have exhibited significantly higher values at the shore stations, apparently because of slough-off from littoral vegetation. Table V-4 is a summary of some data from the three stations in Anderson-Cue Lake and the two stations in McCloud Lake. Because of the large number of samples even the small differences shown for some parameters are statistically significant, but it seems unlikely that the differences would be ecologically significant or that they would change one's opinion about the lakes' homogeneity.

A detailed study of the lateral variations in ammonia and ortho-phosphate was conducted in January, 1968, and gives further evidence of the experimental lakes' comparative homogeneity. This is not to say that there are no differences at all. Figure V-8 shows a slight trend for higher ammonia near the southern shore. In general, ortho-phosphate was higher in shore areas than in the lake center (Figure V-9), but values for the southern shore were the lowest in the lake. The high ortho-phosphate values in the northwest portion of the lake probably represent a minor source of pollution from cattle grazing in this area during this period. The results indicate that the routine stations are representative of the conditions throughout the lakes within the limits of accuracy desired for this project. A detailed survey of the area surrounding the nutrient outfall was conducted in January, 1969. The results shown in Figure V-10 imply rapid mixing in the lake since no concentration gradients resulting from nutrient additions were found.

TABLE V-3

COMPARISON OF AVERAGE CONCENTRATIONS OF SOME BIOGENIC PARAMETERS AT THREE DEPTHS IN STATIONS 7 AND 11.

Parameter[1]	Station	N[2]	Year	Top Mean	Top S.D.[3]	Mid Mean	Mid S.D.[3]	Bottom Mean	Bottom S.D.[3]
pH	7	19	1967	4.67	0.50	4.75	0.64	4.74	0.72
		10	1968	5.20	0.49	5.08	0.24	5.27	0.35
	11	19	1967	4.90	1.12	4.75	1.29	4.70	1.25
		10	1968	4.97	0.31	4.93	0.34	4.92	0.48
TON	7	18	1967	0.41	0.15	0.49	0.20	0.65	0.48
		10	1968	0.33	0.06	0.37	0.09	0.38	0.09
	11	18	1967	0.40	0.19	0.43	0.16	0.50	0.22
		10	1968	0.30	0.06	0.37	0.07	0.38	0.11
PON	7	11	1967	0.15	0.08	0.23	0.20	0.35	0.45
		9	1968	0.17	0.05	0.22	0.07	0.21	0.08
	11	11	1967	0.14	0.23	0.19	0.16	0.26	0.27
		9	1968	0.17	0.06	0.19	0.07	0.21	0.10
NH_3	7	20	1967	0.104	0.057	0.126	0.112	0.102	0.069
		10	1968	0.363	0.199	0.368	0.179	0.393	0.191
	11	20	1967	0.052	0.033	0.060	0.036	0.093	0.077
		10	1968	0.136	0.083	0.133	0.068	0.179	0.097
o-PO_4	7	21	1967	4.0	4.6	5.5	7.0	6.1	8.2
		10	1968	11.5	8.8	12.0	8.9	13.4	11.3
	11	21	1967	3.9	5.8	3.3	4.9	3.1	5.0
		10	1968	7.5	5.4	8.4	5.9	11.9	12.7
t-PO_4	7	18	1967	9.3	9.9	12.8	7.4	11.1	8.2
		9	1968	24.6	29.0	20.1	9.3	24.0	7.4
	11	18	1967	7.7	8.8	9.7	8.2	13.4	9.5
		9	1968	10.6	6.1	12.4	5.4	18.1	15.7

---

[1] Values for total organic nitrogen (TON), particulate organic nitrogen (PON) and ammonia in mg N/l; ortho and total phosphate in µg P/l.

[2] N = number of determinations. Data from 1968 are for January to October, while data from 1967 are for entire year.

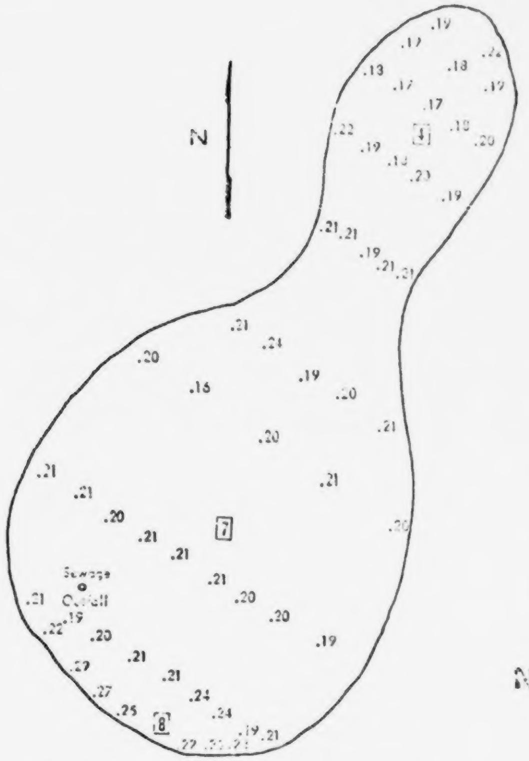
[3] S.D. = standard deviation = $\sqrt{\frac{(x-\bar{x})^2}{N-1}}$. These are standard deviations of the results from the particular station and depth for the given year and reflect the annual variability rather than the analytical precision of the test. They are presented primarily to indicate the former rather than for further statistical testing.

TABLE V-4

COMPARISON OF AVERAGE CONCENTRATIONS OF SOME BIOGENIC PARAMETERS AT THE ROUTINE SAMPLING STATIONS

		Anderson-Cue Lake			McCloud Lake	
Parameter[1]	Year	Station 4	Station 7	Station 8	Station 11	Station 12
pH	1967	4.70	4.72	4.76	4.78	4.64
	1968	5.10	5.18	5.15	4.94	5.03
	1969	4.80	4.83	4.77	4.98	4.98
Acidity	1967	3.5	3.6	3.3	4.1	3.1
	1968	2.8	3.0	2.9	3.3	2.6
	1969	3.5	3.3	2.9	2.9	2.4
TON	1967	0.54	0.52	0.62	0.44	0.48
	1968	0.39	0.36	0.59	0.35	0.49
	1969	0.35	0.29	0.27	0.34	0.39
PN	1967	0.38	0.24	0.37	0.20	0.26
	1968	0.21	0.20	0.24	0.19	0.29
	1969	0.22	0.18	0.16	0.13	0.22
NH_3N	1967	0.101	0.111	0.112	0.068	0.064
	1968	0.356	0.374	0.337	0.149	0.121
	1969	0.190	0.215	0.198	0.070	0.074
NO_3N	1967	0.043	0.040	0.041	0.024	0.019
	1968	0.097	0.090	0.088	0.058	0.064
	1969	0.075	0.078	0.079	0.022	0.025
O-PO_4	1967	3.9	5.2	4.2	3.7	2.9
	1968	12.1	12.3	13.3	9.2	7.6
	1969	4.3	2.6	2.9	3.7	3.1
t-PO_4	1967	11.7	11.1	11.6	10.3	9.2
	1968	24.2	22.8	22.8	13.7	15.3
	1969	19.4	16.4	19.3	15.0	20.0
COD	1968	8.4	9.7	20.7	11.4	8.5
	1969	5.64	5.64	3.76	5.64	3.76
BOD	1967	0.86	0.89	1.83	0.96	0.73
	1968	1.14	0.80	1.33	0.58	1.54
	1969	0.74	0.38	0.19	0.48	0.16

[1] Acidity in mg/l as $CaCO_3$; ortho and total phosphate in µg P/l; all other values in mg/l. PN stands for particulate organic nitrogen.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7
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Sewage
Outfall
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.24
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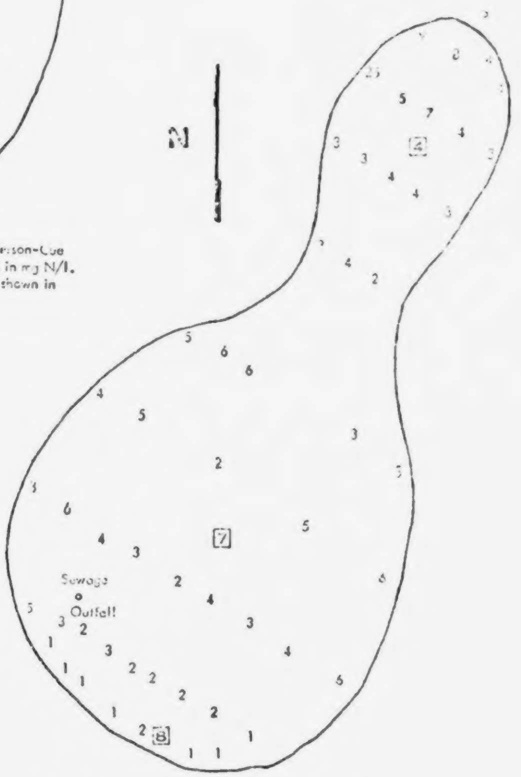
Figure V-8. Lateral Variations of Ammonia in Anderson-Cue Lake, January, 1968. Concentrations in mg N/l. Locations of routine sampling stations shown in blocks.


N
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3
6
4
3
7
5
Sewage
Outfall
2
4
6
5
3
2
3
1
3
4
1
1
2
2
2
6
1
2
2
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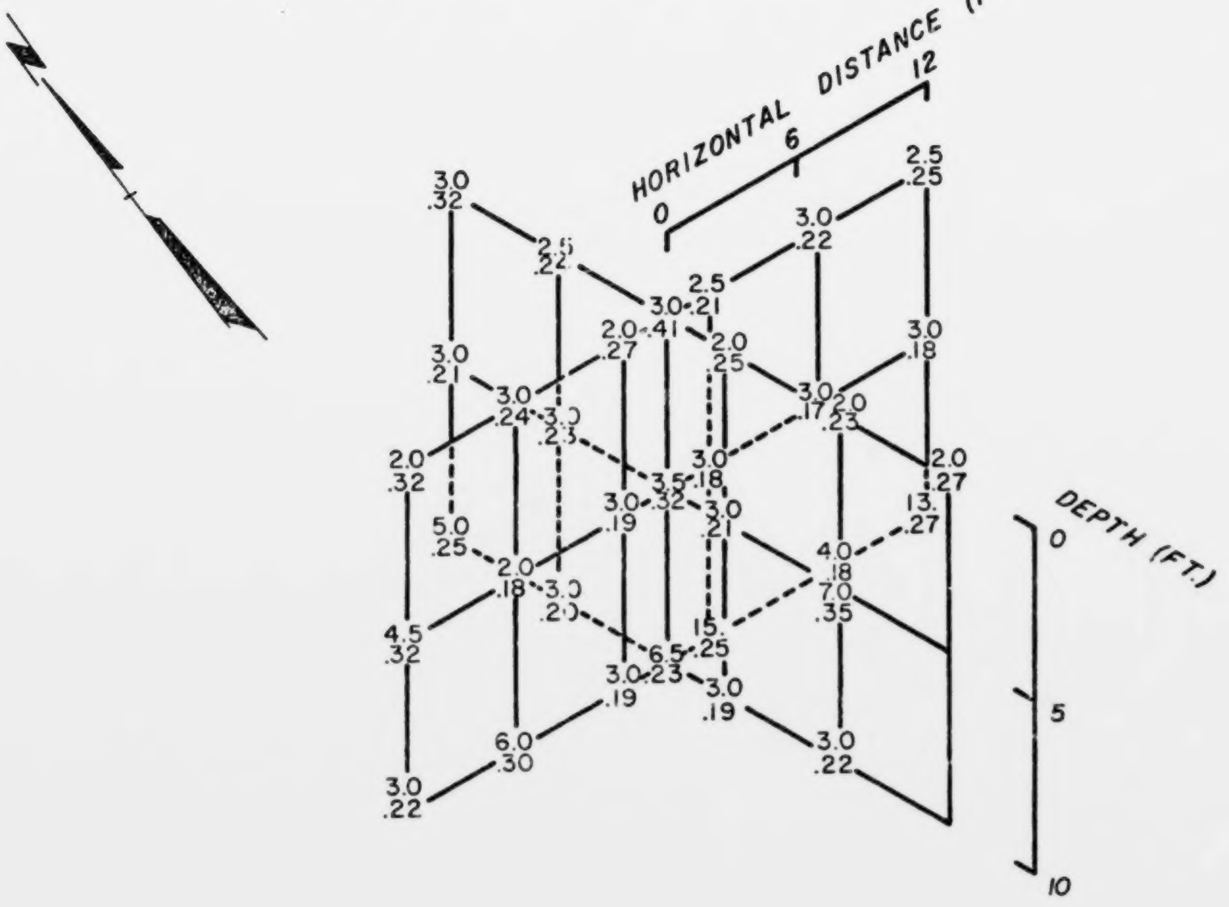
1
1
1

Figure V-9. Lateral Variations of Ortho-Phosphate in Anderson-Cue Lake, January, 1968. Concentrations in µg P/l. Location of routine sampling stations shown in blocks.


HORIZONTAL DISTANCE (FT.)
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6
12
DEPTH (FT.)
0
5
10
3.0 .32
2.5 .22
3.0 .21
2.0 .41
2.5 .21
3.0 .22
2.5 .25
2.0 .27
2.0 .25
3.0 .18
3.0 .21
3.0 .24
3.0 .23
3.0 .17
2.0 .23
2.0 .32
3.0 .18
3.5 .32
2.0 .27
3.0 .19
3.0 .21
13. .27
5.0 .25
2.0 .18
4.0 .18
3.0 .20
7.0 .35
15. .25
4.5 .32
6.5 .23
3.0 .19
3.0 .19
6.0 .30
3.0 .22
3.0 .22

Figure V-10. Ammonia and Phosphorus Concentrations Around Nutrient Outfall -- January 1969.

Several diurnal studies in which samples were taken every hour or every two hours over a 24 hour period have also been made, but in most cases the small variations appear random rather than cyclic. A few parameters do show a measurable diurnal variation; Figure V-11 illustrates this behavior for several biogenic species during a diurnal study from January 31 to February 1, 1968. As Anderson-Cue Lake becomes further enriched and more productive, biogenic species will undoubtedly show greater diurnal periodicity, and studies of the lake's diurnal variations may be a useful indicator of the lake's advancing eutrophy.

Sediment Studies

Sediments may exert considerable influence on the eutrophication process, both as nutrient sources and as nutrient sinks. Furthermore, they can exert large oxygen demands on the overlying water and provide a home and substrate for organisms which spend all or part of their life cycles as benthos. A variety of studies has been undertaken to provide a better understanding of the role of lake sediments in eutrophication.

As a first step, chemical characteristics and variations in sediment types have been determined for the study lakes. Representative results for Anderson-Cue Lake are shown in Figures V-12 through V-14. Several sediment types occur in the lake: near shore, the bottom is sand covered with a thin layer of loose detritus and periphyton. In parts of the deep regions, peat-like sediments are evident with much fibrous and undecomposed plant material. In other areas the sediments are darker and finer grained, more like the ooze or sapropel of alkaline lakes. The sediments of McCloud Lake have not been as well characterized, but peat-like sediments are less in evidence there. The results indicate that sediments from these lakes are actually higher in nitrogen and phosphorus than sediments from some eutrophic lakes. For example, sediments from Lake Mendota, Wisconsin, have from 200 to 1200 ppm phosphorus and 2000 to 14,000 ppm total organic nitrogen (Hasler, 1963). The sediments in this alkaline lake are over 30 percent precipitated calcium carbonate, whereas those in the lakes of this study are composed largely of organic matter. The absence of carbonate deposits in the sediments of the study lakes permits volatile solids determinations to approximate the organic content of these sediments. The high values in Figure V-14 indicate the largely organic nature of these sediments.

The sediments in the study lakes are obviously enriched with nitrogen and phosphorus compared to the overlying water and thus represent potential nutrient sources. However, most of the nitrogen is present in the organic form rather than as free ammonia (Figure V-12), and most of the phosphorus is also bound (presumably organic) rather than free ortho-phosphate (Figure V-13). Leaching and incubation studies undertaken to reveal the importance of sediments in nutrient storage and release must consider the wide variations in available nutrient content of the various sediments in the lake as well as the

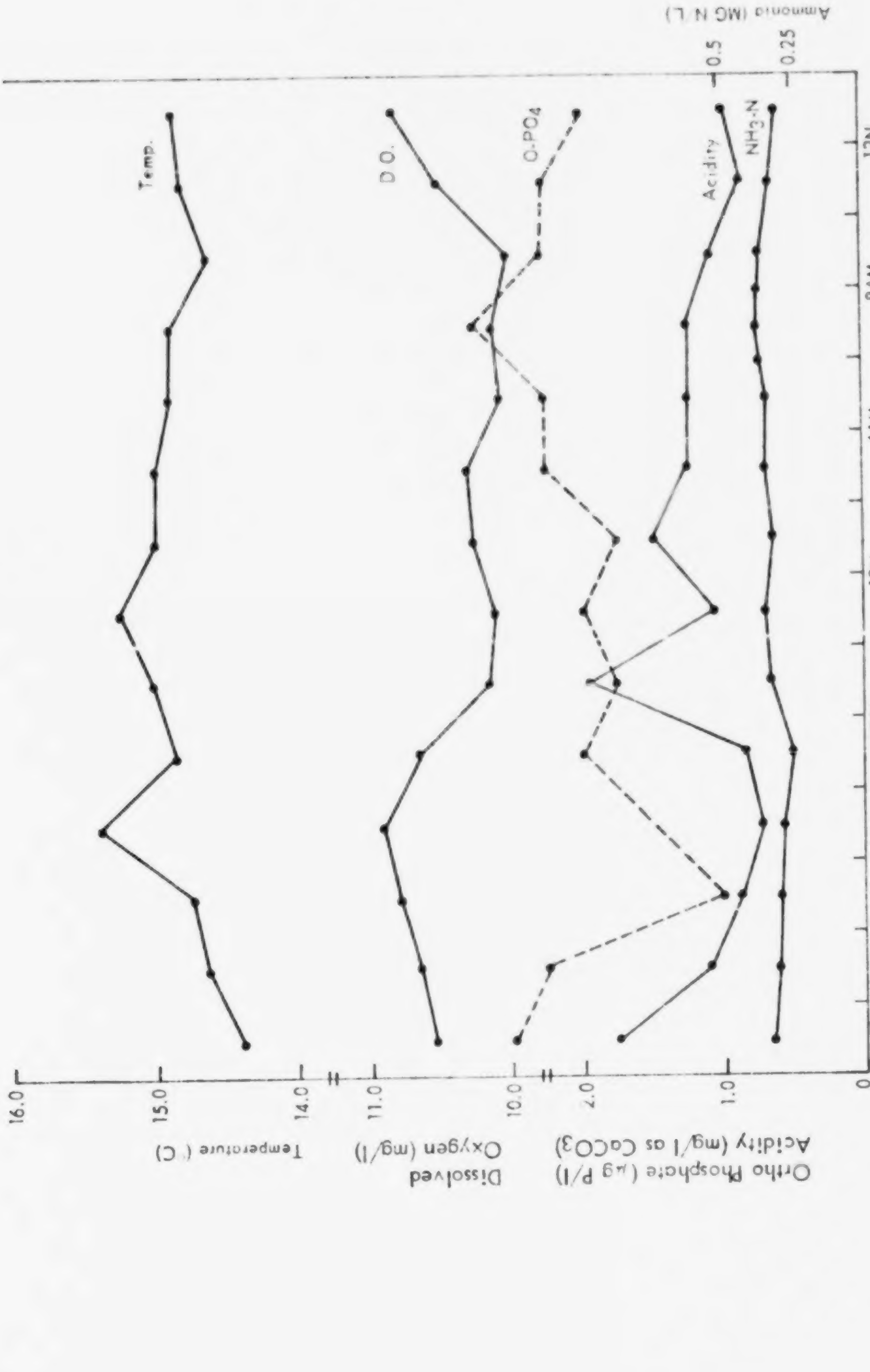
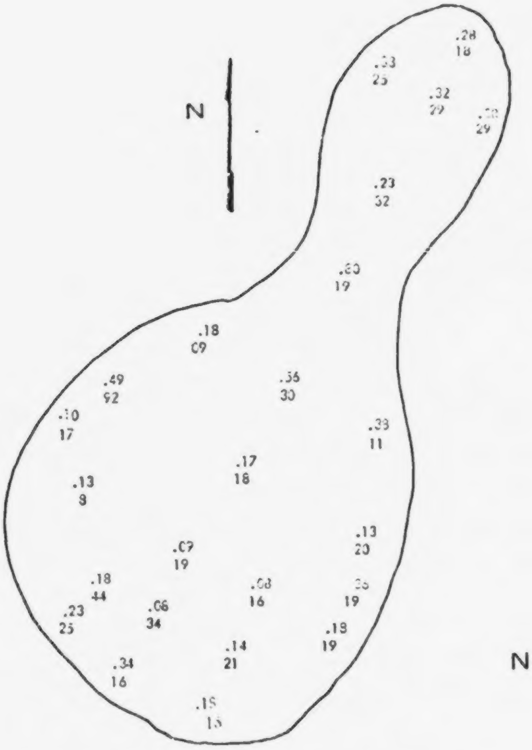


Figure V-11. Diurnal Variations in Anderson-Cue Lake.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18
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8
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20
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19
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44
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16
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19
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25
.06
34
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15

Figure V-12. Nitrogen in Anderson-Cue Sediments. Top number is ammonia; bottom number is total organic nitrogen. Values in mg N/g dry wt. of sediment.

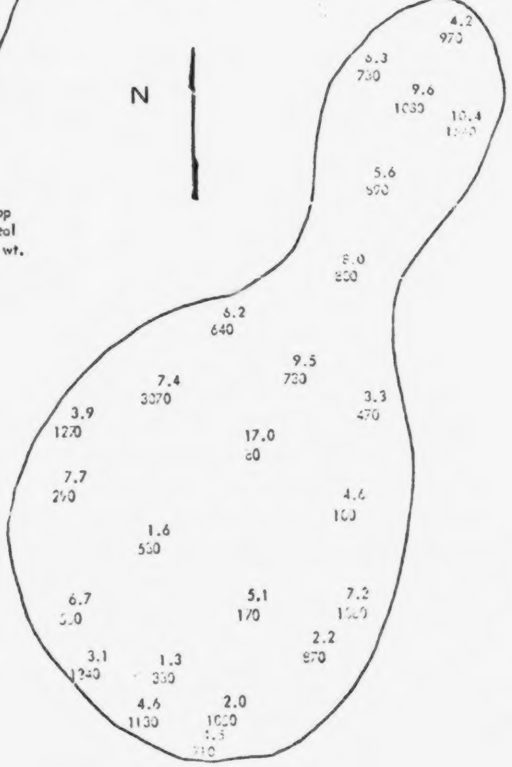
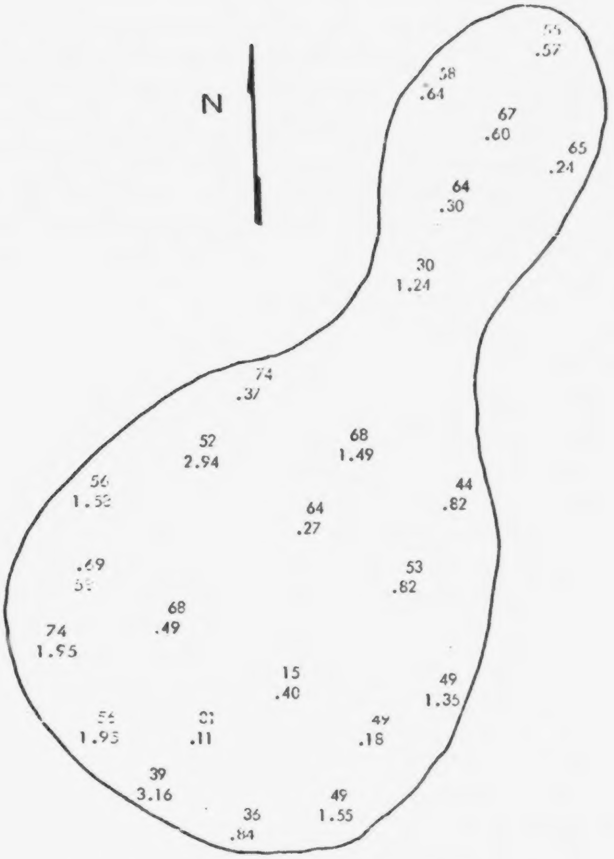

N
4.2
970
6.3
730
9.6
1030
10.4
5.6
590
8.0
800
6.2
640
9.5
730
7.4
3070
3.3
470
3.9
1270
17.0
60
7.7
290
4.6
100
1.6
530
6.7
500
5.1
170
7.2
1500
2.2
970
3.1
1240
1.3
330
4.6
1130
2.0
1000
4.5
710

Figure V-13. Phosphate in Anderson-Cue Sediments. Top number is ortho phosphate, bottom number is total phosphate values in µg P/g dry wt. of sediments.


N
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.57
58
.64
67
.60
65
.24
64
.30
30
1.24
74
.37
52
2.94
68
1.49
56
1.53
44
.82
64
.27
.69
59
53
.82
68
.49
74
1.95
15
.40
49
1.35
56
1.93
61
.11
49
.18
39
3.16
49
1.55
36
.84

Figure V-14. Percent Volatile Solids (Top Number) and Total Iron (Bottom Number) in Anderson-Cue Sediments. Iron values in mg Fe/g dry wt. of sediment.

varying opportunities for transport from sediment to water afforded at different locations in the lake. For example, bottom currents are comparatively slow in the center or deep portions of the lakes and nutrient exchange may be a diffusion-controlled phenomenon. On the other hand, the thin sediment layer in the sandy littoral areas is frequently and easily mixed with the overlying water by wind-generated currents and waves and by movement of fish. Nutrient release from these sediments is probably controlled by metabolic rates rather than by physical factors. The overall question of nutrient exchange between sediments and water (in either direction) is extremely complex and a completely satisfactory answer is perhaps beyond the "present state of the art".

A variety of sediment exchange experiments, including laboratory and in situ studies, have been undertaken or are presently underway or planned. Some initial results of a laboratory incubation study are shown in Figures V-15 and V-16. Sediment from the middle of Anderson-Cue Lake was incubated in 10 liter bottles under varying conditions, and ammonia and ortho-phosphate in the over-lying water was followed over a period of 20 days. About 0.5 liters of sediment was placed in each bottle. Incubation was conducted in the laboratory at 22°C under conditions of (artificial) laboratory lighting. One bottle (A) was incubated under the above conditions; a second bottle was treated similarly except that light was excluded (C), a third bottle (B) was continuously purged with nitrogen to maintain anoxic conditions and a fourth bottle (D) was stirred to keep the sediment mixed with the water. Changes in the ammonia content of the overlying water are shown in Figure V-15. Anoxic conditions allowed more ammonia leaching in bottle (B) than in the oxygenated control (A). However, stirring was more effective and maximum ammonia was released immediately. A similar situation occurred with ortho-phosphate (Figure V-16). Anoxia induced the release of considerably more phosphate than oxygenated conditions in the control. The dark bottle showed consistently lower ortho-phosphate than in the control, but the trend was similar. Again mixing was most effective in liberating phosphate. The maximum phosphate was released almost immediately and the concentration declined about 50 percent over the 20 day incubation. It is obviously premature to extrapolate these results to the in situ role of sediments in nutrient recycling. But it would seem that mixing is the most effective mechanism to release sediment nutrients into the water if that were desired. Alternately it is apparent that the single most effective means of limiting release is prevention of mixing. In deep lakes relatively little mixing occurs. However, during periods of high winds, sufficient currents may be generated in shallow lakes and littoral zones of deeper lakes to stir sediments with the water and release considerable amounts of nutrients.

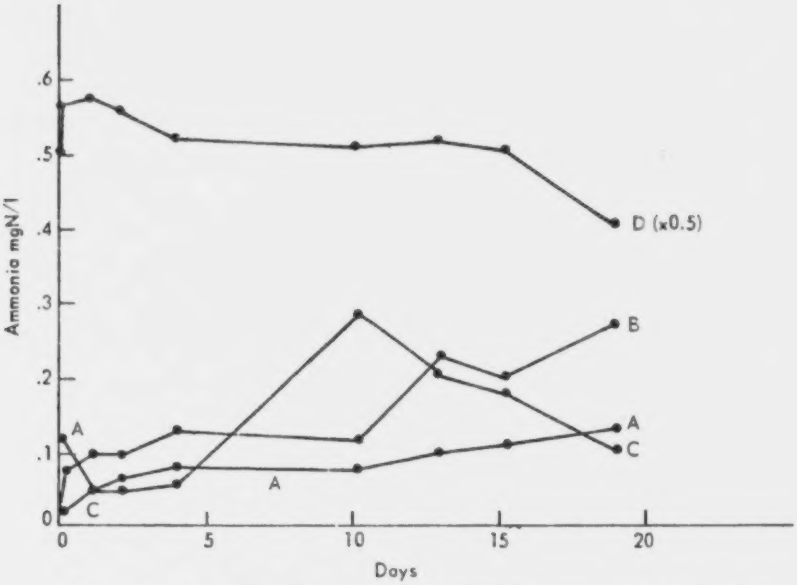

Figure V-15. Temporal Changes of Aqueous Ammonia in Lake Water Incubated With Sediment Under Varying Conditions: A, control; B, anoxic; C, dark; D, stirred.

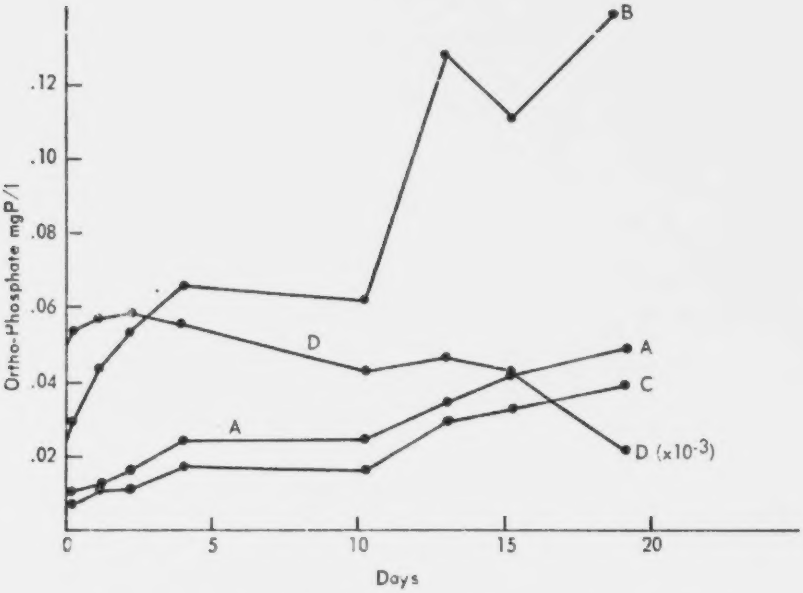

Figure V-16. Temporal Changes of Aqueous Ortho-Phosphate in Lake Water Incubated With Sediment Under Varying Conditions (see Figure V-15 for key).

SECTION VI

BIOLOGY

Introduction

Biological studies of Anderson-Cue and McCloud Lakes have included: (1) the species, succession and productivity of algal forms, (2) the standing stock of phytoplankton, (3) limiting nutrients for phytoplankton growth, (4) standing crop estimates of littoral vegetation, and (5) production estimates of the zooplanktivorous fish Labidesthes sicculus. In addition monthly diurnal variations in primary productivity have been noted along with plant pigment levels as a measure of algal biomass. Two special 10 day studies dealt with an analysis of environmental factors affecting primary production (Brezonik et al, 1969). The methods for these procedures are outlined in Appendix B.

Methods Developed

Except for the special techniques described below, all biological observations in this study were carried out using standardized techniques such as outlined in Standard Methods for the Examination of Water and Wastewater (1965) and FWQA Analytical Techniques for the National Eutrophication Research Program (June, 1969). Special techniques to determine population dynamics and productivity of zooplankton were developed and are described below.

Zooplankton samples were taken from January, 1967 through December, 1968, in Lake Anderson-Cue and from May, 1967, through December, 1968, in Lake McCloud. From January to August, 1967, samples were taken bi-weekly with a Wisconsin closing plankton net (125 meshes/inch) towed horizontally for a known distance at three depths corresponding to just below the surface, mid-depth, and just above the bottom. Aliquots from these samples were counted; counts were adjusted to No./m^3 and integrated over depth to obtain No./m^2. After August, 1967, weekly samples were taken with a vertical-tow plankton net (125 meshes/inch) pulled from bottom to surface. When using the vertical-tow net, samples were taken from three stations in the lake and each sample concentrated to 35 ml. The three samples were combined, mixed thoroughly, and a sub-sample of 35 ml taken from the mixture for preservation with formalin and for counting. This procedure provided a physical means of averaging samples from three areas of the lake while counting only one sample, thus providing a more representative sample from the lake.

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Zooplankters were counted using a compound microscope at a magnification of 21 diameters. Each sample was shaken thoroughly; a 1 ml aliquot was then taken with a graduated syringe and placed in a Sedgewick-Rafter counting chamber. Three such aliquots were counted for each sample and all zooplankters in the chambers were identified and counted. Occasionally, when phytoplankton was especially numerous, it was necessary to dilute a sample before counting. Counts from samples taken with a vertical-tow net were converted directly to No./m^2 based on the area of the net mouth; e.g., a net with a 0.2m^2 mouth area towed from bottom to surface would collect the plankton under 0.2m^2 of lake surface.

Biomass determination. To determine the mean individual biomass of a zooplankton species, individuals were sorted from a sample under a dissecting microscope, blotted, dried under vacuum desiccation, and weighed on a calibrated quartz helix. From 5 to 200 dry individuals were weighed at a time to get an adequate deflection of the helix. To avoid bias in unconsciously selecting only the larger individuals, several drops of plankton sample were placed on a watch glass and all individuals of a species were removed for drying. The total individuals weighed of any species were taken from several samples in case a species might average larger in some samples than in others. Due to the small size and relative scarcity of planktonic rotifers in these lakes, only the biomass of the most abundant species, *Keratella americana*, could be determined. For conversion of population estimates to biomass, all other rotifers were considered to be the same size as *K. americana*. The obvious error involved is quite small in terms of total zooplankton biomass since *K. americana*, when abundant, comprised only ca. 7 percent of the total biomass.

After the mean dry weight/individual of a species had been determined, the species biomass for any sample date was calculated by multiplying individuals/m^2 by mg/individual. The species biomasses were summed to obtain total zooplankton biomass.

Secondary production. An estimate of yearly production was made for each zooplankton species except that rotifers other than *K. americana* were lumped. In order to put limits on secondary production, three calculations were made: a minimum estimate, a maximum estimate, and a "best estimate". The minimum estimate for a species was obtained by summing the net positive change in population size over a year, then multiplying by the average mass per individual of the species. The other two estimates were unrelated to the minimum estimate, except that all were based on the same population data and biomass data.

The classical sigmoid growth curve for a population is described by the equation $\frac{dN}{dt} = rN\frac{(K-N)}{K}$ where:

N = No. of individuals

t = time

r = instantaneous rate of increase

K = carrying capacity of the environment.

If N is very small relative to K the expression $\frac{K-N}{K}$ simplifies to 1.0 and the resulting equation, $\frac{dN}{dt} = rN$ describes the logarithmic phase of the growth curve. In this study N was considered to be very much smaller than K for several reasons:

1. The relative density of zooplankton in oligotrophic lakes such as those studied is very low. For example, maximum cladoceran densities in Anderson-Cue and McCloud are in the order of 50-100/liter. Ward (1940) reported up to 2,000 cladocera/l in a small pond and Borecky (1956) reported 3,500 cladocera/l in Pymatuning Reservoir.

2. Density dependent effects on laboratory populations of Daphnia were not seen by Frank, et al (1957) until densities of 1,000-2,000/l were reached.

3. A plot of r vs. N for data from Anderson-Cue shows no tendency for r to decline as N gets larger. If N were approaching K. r should be approaching zero.

The equation $\frac{dN}{dt} = rN$ can be written in its integrated form: $N_t = N_0e^{rt}$, and taking natural logarithms: $\ln N_t = rt + \ln N_0$, which when $\ln N_t$ is plotted against t, gives a straight line with r as the slope.

In this study logarithms of population were plotted against time and each slope was considered to be an estimate of r over that time period. For any species the maximum positive slope observed was considered to approximate r_m, the intrinsic rate of increase for that species. To determine maximum production, each species was considered to be reproducing at r_m at all times during the year so that observed differences between r and r_m were considered to be due entirely to a variable death rate. The maximum productivity at any time was calculated from the equation:

$\rho_m = N_t \, r_m \, B$, where:

ρ_m = maximum productivity

N_t = population size at time t

r_m = maximum observed instantaneous rate of increase

B = average biomass per individual.

Values of ρ_m were integrated over a year's time to get maximum yearly production.

The "best estimate" of production was determined similarly to maximum production except that all positive r values were used to determine productivity: $\rho = N_t \, r_t \, B$, where:

N_t and B are the same as above

r_t = the observed rate of increase at time t

ρ = productivity

Productivity was integrated over time to get a "best estimate" for yearly production. Finally production values for all species were summed to get total zooplankton production.

Predation. Labidesthes sicculus was considered to be the chief zooplankton predator in these lakes. The population size of L. sicculus was estimated using the Peterson mark-recapture method as described by Ricker (1958). Fish were captured individually at night with dipnets and each fish was immediately marked by clipping a pectoral fin and released. Since L. sicculus will lie at the surface in shallow water on a dark night, the marking procedure was fairly simple. The brief period of handling ensured minimum damage to the fish. Recaptures were made after one week.

At numerous times during the year, samples of L. sicculus were collected with a dipnet or seine and preserved in 10 percent formalin for later analysis. To determine food habits, each fish was measured and its gut contents analyzed. The entire gut was removed, carefully pulled apart, and washed with a few drops of water in a Sedgewick-Rafter counting chamber. All recognizable organisms in the gut were counted under 21X magnification with frequent use of higher magnification to check identification. The counts of zooplankton in the gut were converted to total mass of zooplankton eaten by multiplying the number of each species by the mean individual biomass for the species.

Statistics. Statistical tests were used to evaluate apparent trends in the results. Since sampling frequency was arbitrarily chosen, samples were considered to be random with respect to population sizes or biomass. Total biomass values were assumed to have an approximately normal distribution. In determining correlation coefficients between species, only samples in which both species occurred were used, as inclusion of zero values would constitute a significant departure from a normal distribution and thus invalidate the test statistic "r". All statistical tests used are described by Mendenhall (1967). A significance level of 0.05 was used throughout.

In a related, but independent study, the interactions of littoral zooplankton and their fish predators were studied. The analysis scheme used in this study is described below.

Zooplankton collections were made in each lake every two weeks. Samples were taken in the inner zone (water depth = 0.5-1.0m) with a Van Dorn water sampler (volume = 1.93 l) after vigorous stirring to dislodge organisms from the vegetation and insure random dispersal in the water column. These were concentrated to 32 ml with a plankton net and preserved in one percent formalin. Three one ml aliquots were counted. All cladocera were identified to species. Rotifers were identified to genera. Copepoda and their nauplii were counted, but not identified. Counts were converted to organisms per m^2 by multiplying the organisms per m^3 by depth (m) at the sampling site.

Etheostoma fusiforme and *Heterandria formosa* were collected every two weeks with a dipnet in the same area as the plankton sample. Five fish of each species were taken from each lake and preserved in 10 percent formalin. Due to the small size of the fishes and the lack of a definitive stomach in *H. formosa*, the entire gut contents were removed and counted. Although total length of each fish examined was recorded, all sizes of both species of fishes fed on the same organisms.

The contribution of each species or group of zooplankters to the diet was expressed as its percentage of the total organisms eaten. Due to the large number of species and the difficulty in measuring the biomass of individual zooplankters, the contribution of species or groups in terms of proportion of total biomass was not determined. Bi-weekly fish gut analyses were pooled and reported as monthly averages.

During the second year of the study, fish densities were estimated by pulling a wire mesh dredge through specified areas in the littoral at various times during the year.

Gut clearance rate. Laboratory experiments were conducted to determine gut clearance time at 15°C, 20°C, and 30°C for both fishes. Following two weeks of acclimation fish were placed in a feeding chamber containing zooplankton. After 30 minutes they were returned to their original aquaria. At intervals of 1 or 1/2 hour, five fish were removed and their gut contents were examined, until the microorganisms were in the lower portion of the gut and were no longer identifiable.

Algal succession. The variety and succession of algal forms have been followed both along the marginal shallow bottom and among the littoral vegetation of both lakes. Comparisons have been made with the kinds and numbers in the open surface water and with those close to the water-sediment interface at maximum depth. This early work which began in 1965 was reported previously (Lackey and Lackey, 1967) and serves as a baseline for future changes in the microbiota as nutrient enrichment continues.

Both lakes are similar in many respects. For example *Synura uvella* occurs in both lakes and typically is more abundant in the deep open water areas. Many species of colorless *Euglenophyceae* are found in the lakes and each body of water supports a bloom of *Dinobryon* at least once during the late winter. Both support a varied dinoflagellate flora. Generally the low population of photosynthetic forms indicates limited algal growth substances and the low numbers of zooflagellata and ciliates as well as the paucity of open water euglenids indicates the low organic content of the lake waters.

As the experimental lake continues to eutrophy the greatest fluctuation in species will be those which occur in very small numbers. A question to be answered is whether the crop of *Dinobryon*, *Synura*, *Peridinium umbonatum* and *Stentor amethystinus* will increase considerably as enrichment proceeds or whether species now encountered infrequently will increase and supplant the present common organisms.

Rhode as discussed in Hutchinson (1967) has reported the disappearance of *Dinobryon* with increasing phosphorus levels. It will be interesting to note the effect of rising phosphorus levels in Anderson-Cue Lake on the indigenous *Dinobryon* population. Blooms of these chrysophytes occur annually between December and February. Data for plankton analysis are presented in the Appendix. A summary of this phase of the research showing the number of species and frequency of occurrence is outlined in Table VI-1. Generally the total species of each lake is similar. This is so because nutrients have been added so that biotic changes can occur gradually and it is still early to note marked differences. Some species variation obviously does exist between the two lakes, but presently we can not determine whether this is a reflection of nutrient enrichment. The plankton data as presented should be considered as representative for the soft, acid, sand bottom lakes found in north central Florida.

Appendix C reflects the percent occurrence of species during 1967 and 1968. The data are qualitative since population and biomass estimates were infrequently carried out. The extensive list of species includes littoral as well as open water forms and therefore forms not usually associated with the open water plankton are included. A great many inshore forms are part of the periphyton. This community although an important part of the lake biota, often is not considered in limnological investigations. However, the periphyton can be the most productive plant community in a lake system as was observed by Wetzel (1962) in the study of Borax Lake in California.

TABLE VI-1

GROUPS OF MICROSCOPIC ALGAE AND PROTOZOA IN DETAILED ANALYSES
ON FIVE DATES IN 1967-68 IN McCLOUD AND ANDERSON-CUE LAKES,
AND THE NUMBER OF OCCURRENCES.

		McCloud		Anderson-Cue	
Organism Group	Total Species	No. Species	No. Occur.	No. Species	No. Occur.
Sulfur Bacteria	2	1	3	2	4
Blue Green Algae	26	24	23	21	33
Green Algae	58	48	117	39	101
Volvocales	7	7	13	2	5
Euglenophyceae	39	23	40	29	50
Cryptophyceae	5	5	18	5	14
Chrysophyceae	23	23	33	18	24
Chloromonadida	4	2	6	4	8
Dinoflagellata	17	17	36	14	31
Bacillarieae (Diatoms)	7	5	8	4	6
Rhizopoda	31	21	40	24	33
Zooflagellata	22	18	23	15	19
Ciliata	59	42	82	41	82
Totals	300	236	472	218	410

Effect of Nutrient Enrichment

Anderson-Cue has been enriched with nutrients since March, 1967. The 34 month regimen included loading with 300 gallons of secondary sewage effluent with supplemental nitrogen and phosphorus to achieve 2.48 kg N and .212 kg P weekly. As of August, 1970, approximately 387 kg N and 33.00 kg P have been added. Lake response during this time has been negligible for most of the routine chemical and biological parameters. Table VI-2 shows yearly averages for some biogenic parameters in both lakes for the period 1967-1969. A mean for February and April 1970, is also included. As the data show, using the mean for all years, a significant difference does occur for chlorophyll a, but among no other parameters. However, averages for individual years relate increased ammonia and primary production as well as plant pigments as response parameters.

Figure VI-1 and Table VI-3 A,B summarize phytoplankton production levels for a three year period beginning in 1967. The curves for the two lakes with regard to their productivity--approximate one another rather closely showing a similar summer--early fall maximum. Annual production estimates in Anderson-Cue Lake show essentially no differences with Lake McCloud. The level of fixed carbon at the end of 1969 was 58 grams/m^2 for Anderson-Cue compared to 60 grams for the control lake. Bioassays using C^{14} techniques as well as Provisional Algal Assay Procedures (PAAP) show phosphorus to be a principle limiting nutrient in both lakes.

Certain comparisons can be made with other nearby lakes in Alachua County which demonstrate eutrophic conditions. Productivity determinations were made on these lakes in November, 1968, using an enclosed box with a constant light source at an ambient temperature of 20°C.

Hawthorne	55.45*
Newnan's	53.55
Bivens Arm	77.54
Orange	43.01
Wauberg	124.30
McCloud	21.83
Anderson-Cue	11.52

*mg C fixed/m^3-hour

These data indicate that both lakes in the experimental system are less productive and that Anderson-Cue will require much more nutrient enrichment to reach a level comparable to other eutrophic lakes in this area. Interestingly enough comparative productivity of Lake Apopka and Lake Dora in Orange and Lake Counties which are recognized hypereutrophic lakes in central Florida is 400 mg/C^3-hr and 1000 mg C/m^3-hr respectively. Both of these lakes support continuous algal blooms throughout the year. In addition the lakes are virtually useless for recreational purposes.

TABLE VI-2

COMPARISON OF AVERAGE CONCENTRATIONS OF SOME BIOGENIC PARAMETERS IN EXPERIMENTAL LAKES 1968-1970

	Anderson-Cue			McCloud	
Parameter	Year	Annual Mean	Grand Mean		
pH	1967	4.72	4.92	4.75	5.02
	1968	5.36		5.03	
	1969	4.75		4.89	
	1970*	4.83		5.42	
Cond[a]	1967	--	38.66	--	35.88
	1968	40.00		38.15	
	1969	38.50		35.00	
	1970*	37.50		34.50	
TON	1967	.54	.36	.45	.34
	1968	.36		.34	
	1969	.30		.32	
	1970*	.23		.26	
NH_3-N	1967	.11	.18	.07	.12
	1968	.39		.11	
	1969	.20		.06	
	1970*	.02		.26	
NO_3-N	1967	.04	.07	.02	.02
	1968	.08		.04	
	1969	.10		.02	
	1970*	.07		.02	
PO_4-P	1967	.005	.007	.004	.005
	1968	.018		.011	
	1969	.002		.003	
	1970*	.002		.001	
Total P	1967	.011	.018	.010	.014
	1968	.026		.014	
	1969	.017		.017	
	1970*	.020		.015	
PP[b]	1967	92.43	134.83	107.18	133.35
	1968	157.44		140.08	
	1969	154.61		152.79	
	1970*	--		--	
Chl a[c]	1967	2.04	4.18	1.63	1.94
	1968	5.17		1.30	
	1969	7.35		2.43	
	1970*	2.15		2.41	

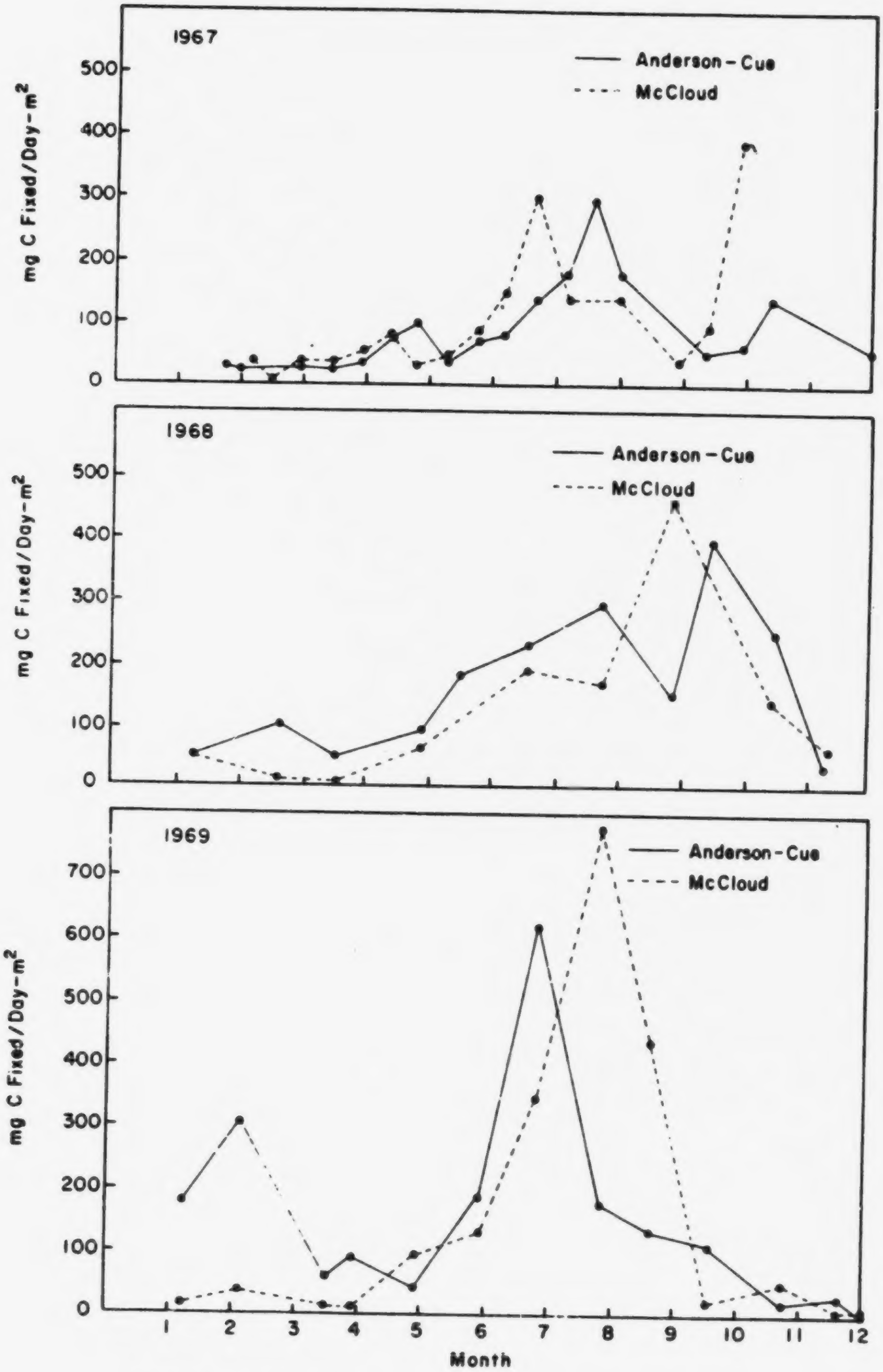
[*] average of February and April

[a] μmho cm^{-1}

[b] primary production mgc/m^2-day

[c] chlorophyll a mg/m^3

Figure VI-1



ANNUAL VARIATION OF PRIMARY PRODUCTIVITY IN ANDERSON-CUE AND McCLOUD LAKES

TABLE VI-3 A

PRIMARY PRODUCTIVITY VALUES FOR ANDERSON-CUE LAKE

	mg C fixed/day--m^3			mg C fixed/day	
Date	Surface	5'	10'	per m^2	Langleys/day
1/24/67	7.18	9.21	12.30	29.84	402
1/31/67	2.30	9.39	9.70	26.44	382
2/28/67	19.70	9.23	6.91	32.56	--
3/14/67	20.80	6.24	13.24	27.28	375
3/28/67	7.47	14.60	5.90	38.40	203
4/11/67	34.80	25.60	21.80	81.40	540
4/25/67	47.30	32.40	22.00	100.80	652
5/9/67	9.53	14.00	7.33	37.60	703
5/23/67	28.90	27.50	8.62	75.60	400
6/6/67	31.60	27.20	23.70	84.00	461
6/20/67	68.40	47.70	10.30	138.80	483
7/7/67	96.00	57.50	42.80	185.20	456
7/19/67	127.50	98.10	70.30	303.20	607
8/1/67	33.80	66.70	33.50	183.60	504
9/12/67	40.10	14.40	6.80	53.60	225
9/26/67	31.90	15.04	35.60	62.60	560
10/11/67	22.70	51.30	43.50	141.60	573
11/28/67	17.00	21.70	15.80	61.20	461
1/9/67	17.40	18.40	6.93	50.20	294
2/21/68	33.10	31.80	48.50	101.00	426
3/19/68	26.70*	15.52*	4.47*	48.20	499
4/29/68	35.91	34.45	1.40	90.00	574
5/16/68	105.63	59.60	9.32	181.60	600
6/18/68	153.34	72.01	6.78	280.80	560
7/23/68	113.16	107.36	5.66	294.00	560
8/27/68	128.52	41.76	9.70	152.00	580
9/16/68	160.90	140.90	8.62	397.00	380
10/14/68	151.08	83.88	11.76	252.50	476
11/11/68	16.29	13.61	4.18	39.00	110
12/11/68	15.64	18.19	16.25	53.00	315
1/6/69	40.40	73.30	17.06	181.40	300
2/3/69	108.65	113.51	37.68	308.40	215
3/14/69	20.39	22.32	9.06	60.50	392
3/31/69*	28.20	34.43	9.64	93.10	490
4/28/69	32.19	14.76	1.33	46.20	573
5/26/69	64.40	74.95	1.39	191.20	358
6/23/69*	274.31	226.97	41.16	635.00	556
7/23/69	157.32	43.06	20.98	182.50	522
8/18/69	161.73	27.00	8.90	137.50	606
9/15/69	64.10	40.38	7.04	116.00	266
10/21/69	12.17	7.21	2.93	21.68	221
11/18/69*	8.43	11.91	11.91	33.00	340
12/15/69	1.12	1.22	0.92	3.45	361
1/14/70	14.74	14.95	5.50	37.32	212
1967 Average				92.43	
1968 Average				157.44	
1969 Average				154.61	

*Values were obtained from diurnal data, calculated by averaging incubation periods at each depth and multiplying by hours of daylight.

TABLE VI-3 B

PRIMARY PRODUCTIVITY VALUES FOR McCLOUD LAKE

	mg C fixed/day--m^3			mg C fixed/day	
Date	Surface	5'	10'	per m^2	Langleys/day
2/7/67	8.28	15.50	7.14	41.10	278
2/14/67	3.27	3.53	3.77	10.72	452
2/28/67	13.80	13.90	7.07	39.36	--
3/14/67	5.21	16.34	13.17	39.20	375
3/28/67	24.92	13.64	36.62	55.00	203
4/11/67	24.90	30.16	23.33	87.30	540
4/25/67	2.00	13.26	6.37	33.28	652
5/9/67	10.50	17.34	23.58	52.80	703
5/23/67	30.86	31.33	22.44	92.00	400
6/6/67	59.50	43.72	67.20	151.80	461
6/20/67	59.56	96.23	169.06	312.00	483
7/7/67	32.69	49.90	37.00	139.00	456
8/1/67	68.03	45.48	19.07	137.00	504
8/29/67	6.49	14.43	7.55	37.64	575
9/12/67	53.78	29.33	13.21	94.60	225
9/26/67	109.59	150.57	37.41	392.00	560
1/9/68	7.70	18.44	15.10	50.40	294
2/22/68	2.10	5.60	4.81	15.64	320
3/19/68	3.14*	3.99*	3.35*	11.54	499
4/29/68	23.14	22.21	15.30	64.20	574
6/18/68	99.12	61.56	28.38	192.00	560
7/23/68	76.73	54.92	32.98	168.80	560
8/27/68	282.26	138.48	64.78	460.00	580
9/16/68	142.10	113.12	69.35	337.00	380
10/14/68	57.48	47.16	30.00	139.00	476
11/11/68	23.48	24.98	12.01	70.30	110
12/11/68	10.99	11.04	8.18	32.00	315
1/6/69	5.63	6.58	5.55	18.60	300
2/3/69	15.66	12.20	8.53	37.50	215
3/14/69	5.87	4.98	5.44	15.40	392
3/31/69*	4.17	5.28	4.82	15.38	490
4/28/69	26.47	38.70	29.92	98.00	573
5/26/69	47.47	43.58	46.50	136.40	358
6/23/69	139.26	117.69	75.35	353.00	556
7/23/69	231.29	251.85	277.10	778.00	522
8/18/69	198.21	144.61	86.53	440.50	606
9/15/69	9.76	9.14	4.20	25.76	266
10/21/69	20.06	17.58	9.35	48.44	221
11/18/69*	6.53	3.37	3.37	12.56	340
12/15/69	2.35	1.43	3.47	6.70	361
1/14/70	6.44	7.58	7.16	21.64	212
1967 Average				107.18	
1968 Average				140.08	
1969 Average				152.79	

*Values were obtained from diurnal data, calculated by averaging incubation periods at each depth and multiplying by hours of daylight.

The comparative production estimates of lakes provide information regarding the trophic status which in turn can be useful in establishing recreational and use potential of surface water. This technique is especially worthwhile in multi-lake studies where surface waters are being examined on a regional basis. In this kind of investigation comparative productivity estimates can quickly determine lakes where algal growth is high and where ecosystem management procedures could be used effectively.

Diurnal variations in integral photosynthesis were recorded monthly during 1968. These data are presented in Figure VI-2. (Horizontal lines indicate rain.) Rather obviously marked variations in integral photosynthesis occurred during 1968 in both lakes. Maximum productivity in Anderson-Cue Lake was noted in September when fixation of carbon amounted to 65 mg/m^2-hr. Highest photosynthesis between the two lakes was observed in McCloud. Fixation rates here reached 80 mg C/m^2-hr at the end of August.

Variations in the vertical distribution of chlorophyll a between McCloud and Anderson-Cue Lakes are presented in Table VI-4 and Figure VI-3. The data are inclusive beginning in January of 1967. Generally the mean value for chlorophyll a at the surface, 5 and 10 foot depths in Anderson-Cue Lake (1.99, 2.00, 2.12 mg/m^3) were comparable to McCloud Lake (1.53, 1.89, 1.46 mg/m^3) during the first year. The standing crop of phytoplankton increased significantly during 1968 in Anderson-Cue water, but remained virtually the same as before in McCloud. Average values of 4.12, 4.12, and 4.41 mg chl a per m^3 were noted in Anderson-Cue Lake at the three depths while McCloud Lake supported an average of 2.14, 2.02, and 2.24 mg chl a per m^3.

Considering seasonal effects and based on integral values chlorophyll a during 1967 gradually increased from a range of 1-5 mg/m^2 during the first four months to levels greater than 15 mg/m^2 in Anderson-Cue during mid-summer and fall, (Figure VI-3). Both lakes had approximately the same phytoplankton biomass based on pigment analyses except for peaks during July and October in Anderson-Cue Lake. At these times chlorophyll in the experimental lake reached a maximum in excess of 15 mg chl a per m^2.

The 1968 data show the divergent characteristics of the two lakes with regard to pigment levels. Chlorophyll a was 5 mg/m^2 or higher at all times during the year. Three peaks were evident. The highest (>25 mg/m^2) occurred in February during a winter flowering of Dinobryon. The others as indicated in Figure VI-3 were observed in May and late July. The spring bloom coincided with growths of Synura.

It is worthwhile noting the significant algal growth response to added nutrients as evidenced in the elevated chlorophyll values. Most frequently chlorophyll a was greater than 10 mg/m^2. These data support productivity data in that these two parameters show the response to nutrient influx far more rapidly than changes in species diversity.

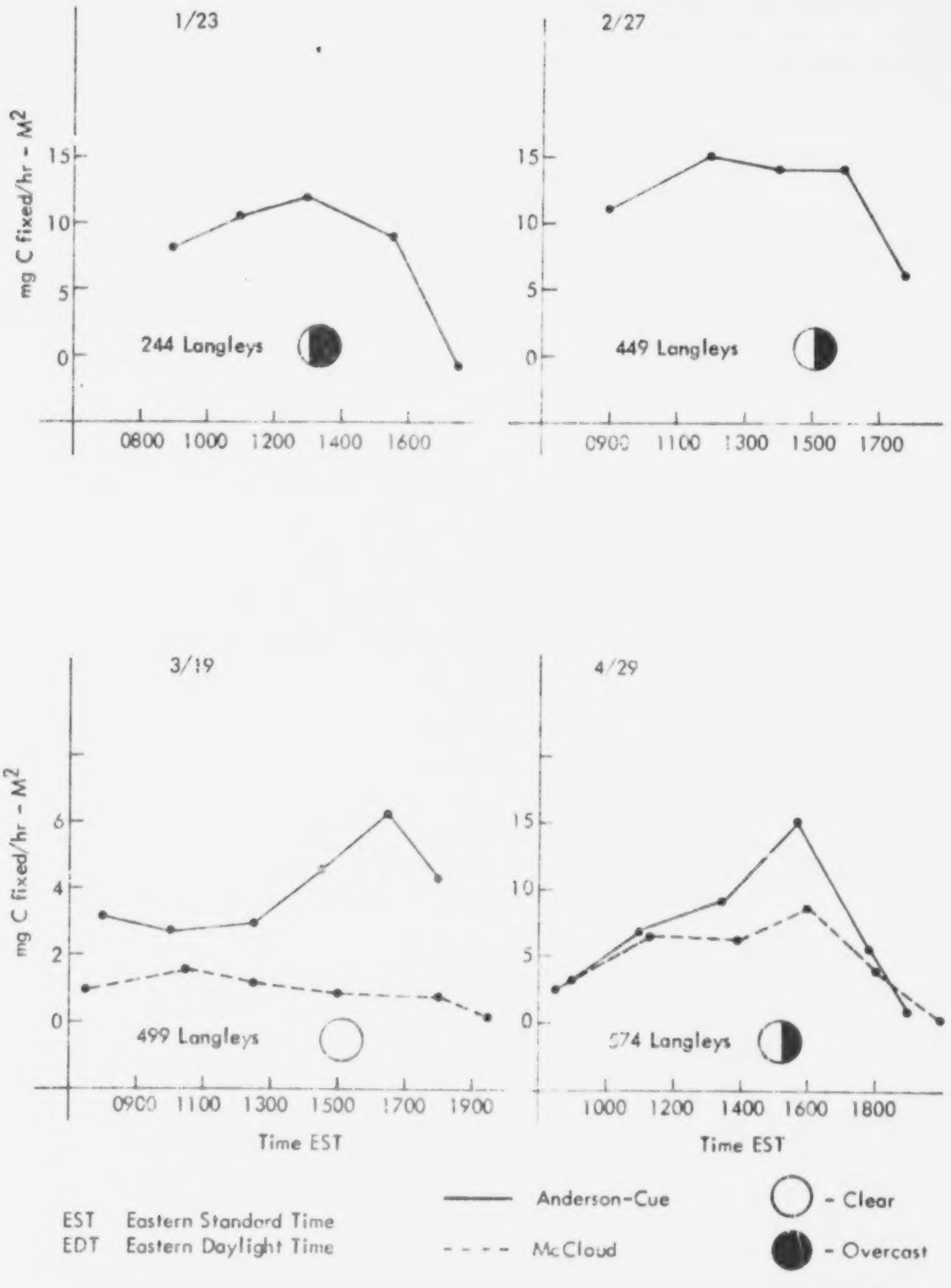


Figure VI-2. Diurnal Variations in Primary Production During 1968.

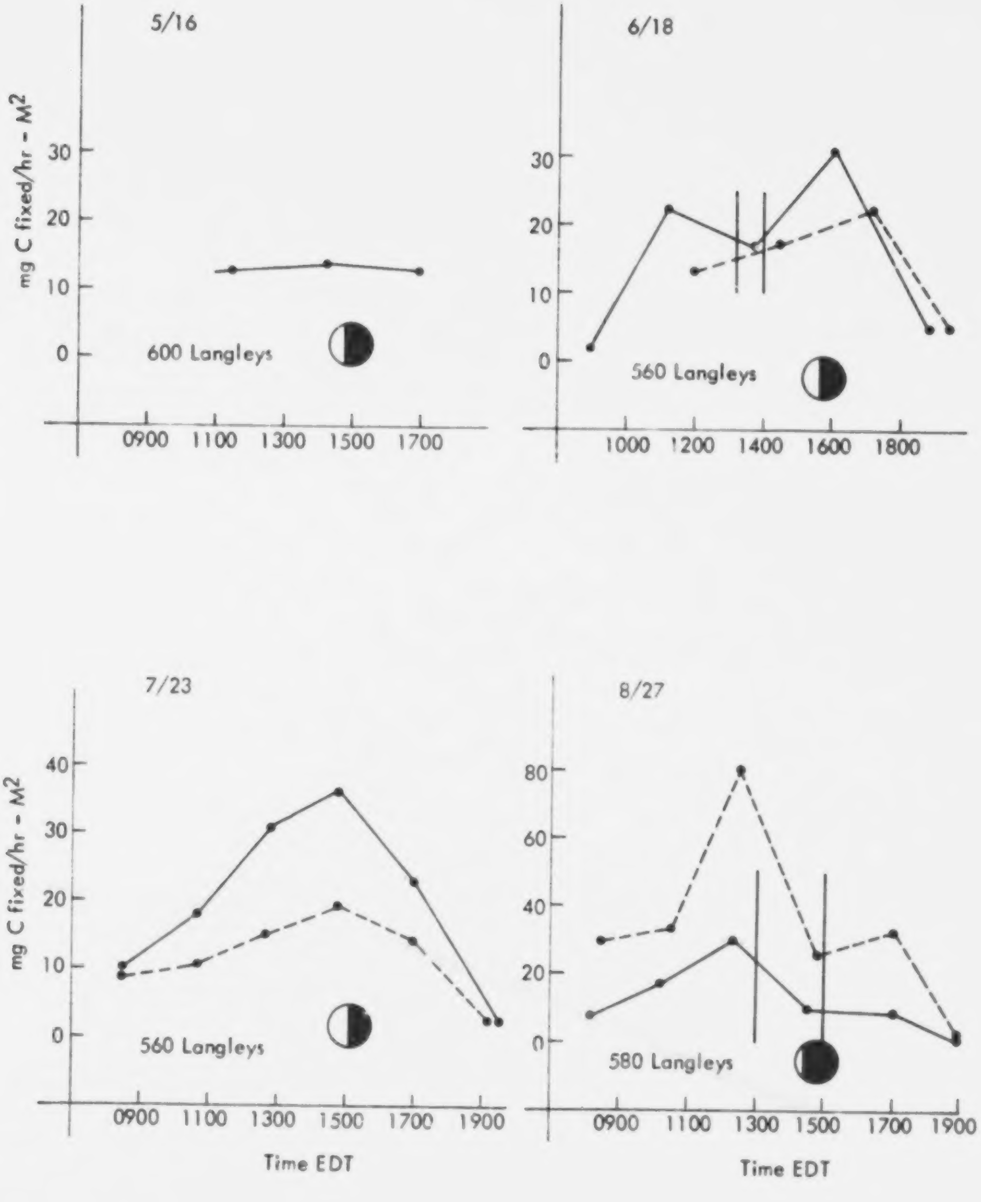


Figure VI-2. (Continued)

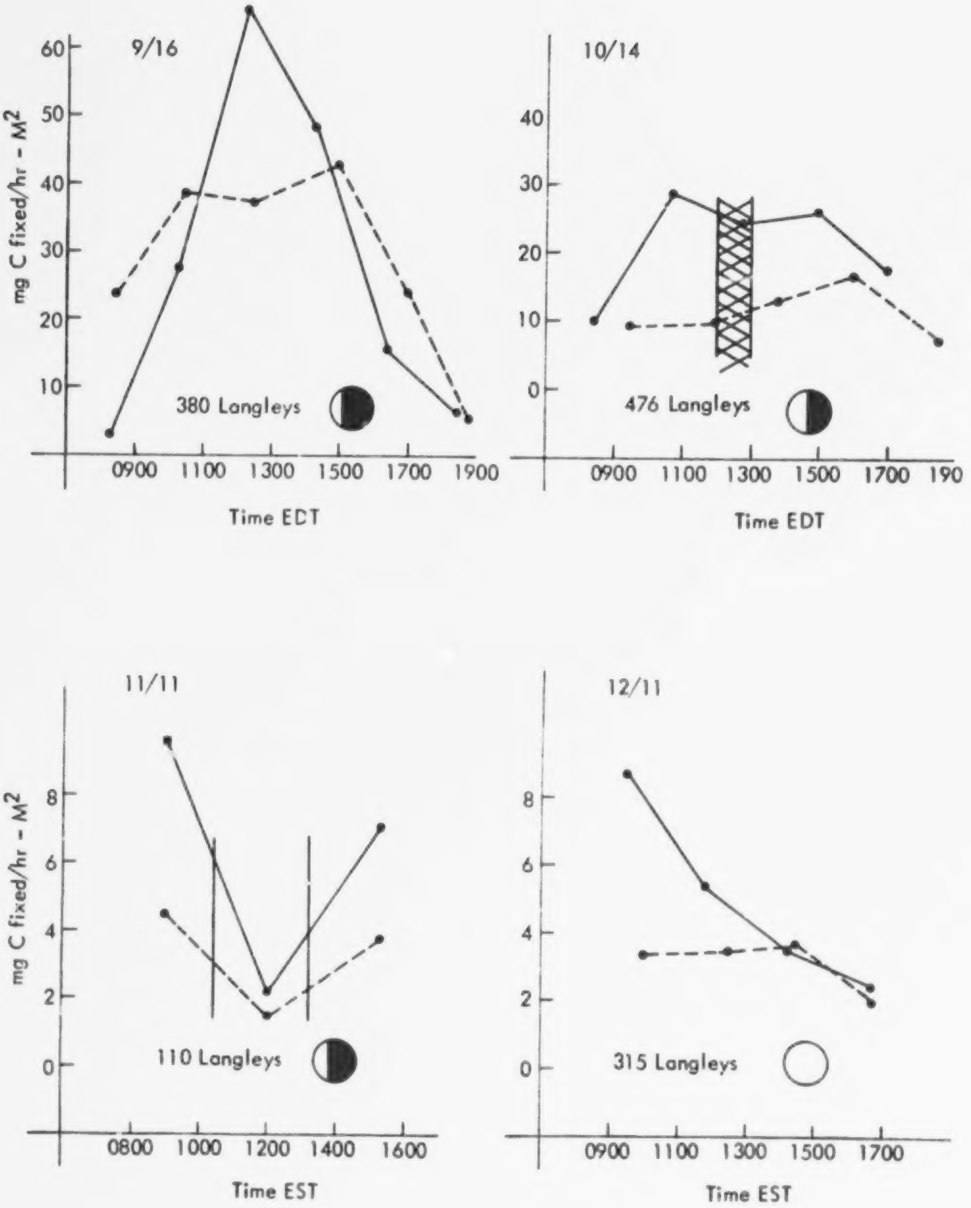


Figure VI-2. (Continued)

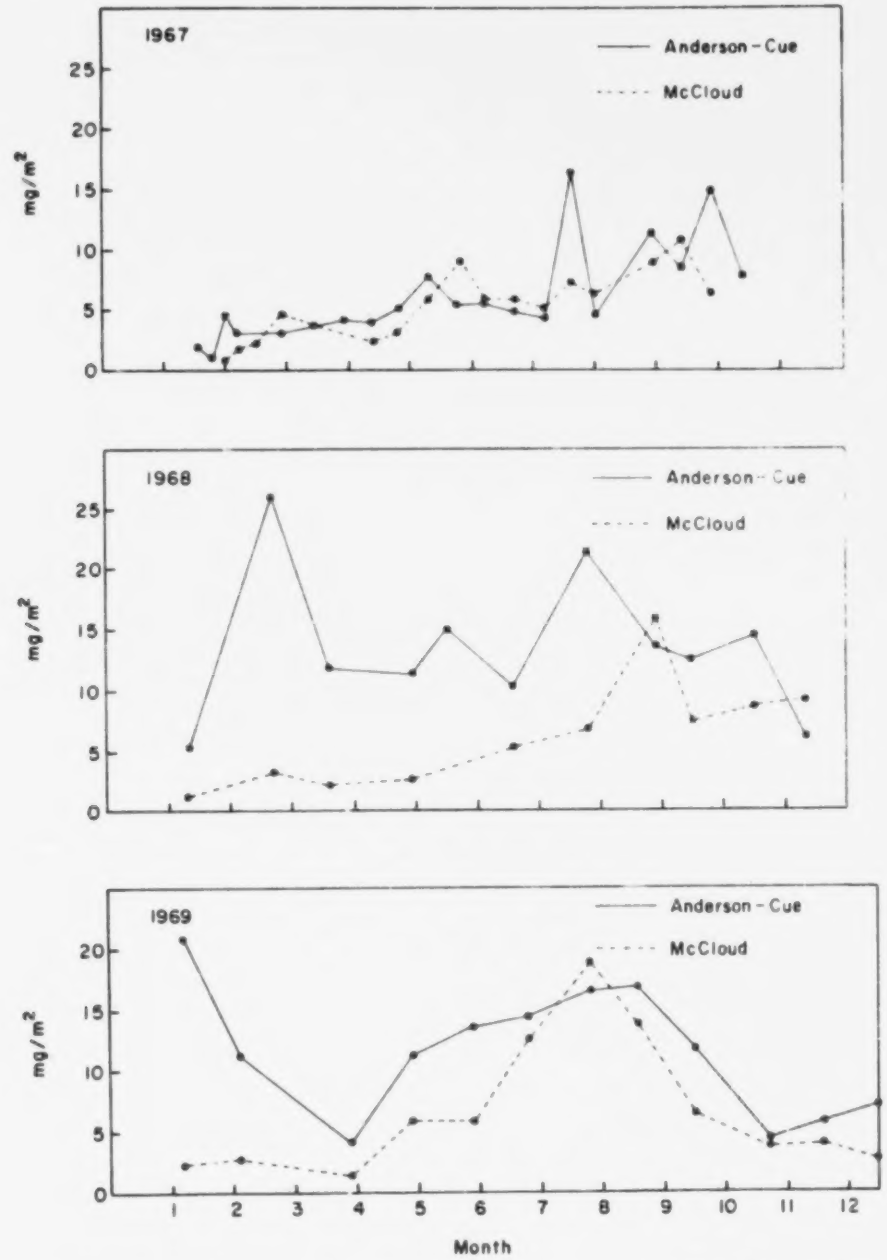
TABLE VI-4

CHLOROPHYLL $\underline{a}$ LEVELS (mg/m^3)
IN ANDERSON-CUE AND McCLOUD LAKES

	Anderson-Cue			McCloud		
Date	Surf	5'	10'	Surf	5'	10'
1/17/67	1.09	0.54	0.83	----	----	----
1/24/67	1.08	0.25	0.25	----	----	----
1/31/67	1.09	1.38	1.12	0.54	0.25	0.25
2/7/67	0.54	1.12	1.12	0.54	0.54	0.83
2/14/67	----	----	----	0.67	0.83	0.80
2/28/67	0.83	1.12	1.08	0.80	1.84	1.08
3/14/67	0.25	1.38	1.60	1.60	1.34	0.54
3/28/67	1.38	1.38	1.37	----	----	----
4/11/67	2.44	1.10	1.34	0.66	0.99	0.57
4/25/67	1.77	1.67	1.57	1.55	0.99	1.12
5/9/67	2.91	2.57	2.55	2.43	1.90	1.90
5/23/67	1.92	1.83	1.67	2.48	3.18	2.56
6/6/67	1.76	1.87	1.97	1.97	1.96	1.86
6/20/67	2.03	1.45	1.89	1.78	1.98	2.32
7/7/67	2.86	1.02	2.03	1.47	2.03	0.68
7/19/67	4.20	5.73	5.64	2.38	2.70	1.49
8/1/67	1.70	1.45	1.36	0.33	2.57	1.59
8/29/67	3.15	4.22	2.57	1.48	3.39	2.48
9/12/67	3.02	2.80	2.80	3.15	3.41	2.81
9/26/67	4.22	4.45	7.14	2.20	2.20	1.99
10/11/67	1.64	2.77	2.55	----	----	----
1/9/68	2.57	0.77	4.47	1.23	0.10	----
2/21/68	7.74	8.77	8.41	0.77	1.12	1.12
3/19/68*	3.00	3.75	5.42	0.68	0.73	0.86
4/29/68*	4.62	3.27	2.56	0.91	0.84	1.01
5/16/68*	5.07	5.06	4.06	----	----	----
6/18/68*	3.57	3.24	3.70	1.77	1.68	1.93
7/23/68*	5.50	7.13	6.97	2.18	2.17	2.34
8/27/68*	4.60	4.66	3.73	5.66	5.30	4.81
9/16/68*	4.18	4.05	4.39	2.62	2.33	2.60
10/14/68*	4.56	4.95	5.50	2.47	2.82	2.69
11/11/68*	2.07	1.90	1.87	3.30	3.02	2.85
12/11/68*	1.92	1.92	1.85	1.98	2.07	2.14
1/6/69	6.74	7.74	6.08	0.72	0.74	0.97
2/3/69	3.82	3.82	4.02	1.18	0.94	0.75
3/14/69	1.80	----	----	0.60	----	----
3/31/69*	1.10	1.40	1.29	0.51	0.48	0.40
4/28/69	4.44	3.71	3.35	2.10	2.02	2.03
5/26/69	4.36	4.39	5.45	1.86	1.73	2.19
6/23/69*	4.45	5.18	5.41	4.37	4.01	4.73
7/23/69	4.66	4.24	9.19	6.24	6.24	6.56
8/19/69	5.17	5.56	6.67	4.71	4.32	5.02
9/15/69	3.75	3.75	4.70	1.88	1.44	1.77
10/21/69	1.84	1.65	1.65	2.11	2.25	2.10
11/18/69*	1.88	2.02	2.15	1.54	1.33	1.22
12/15/69	1.88	2.25	3.28	0.96	1.03	0.90
1967 Average		2.04			1.63	
1968 Average		5.17			1.30	
1969 Average		7.35			2.43	

*Diurnals - Chlorophyll $\underline{a}$ values are an average of approximately 4 samples per day

Figure VI-3



ANNUAL VARIATION OF CHLOROPHYLL a IN ANDERSON-CUE AND McCLOUD LAKES

McCloud Lake during the last half of 1968 had an increased phytoplankton biomass reaching a peak in late August. During the last two years the control lake always supported a maximum population of phytoplankton during August and September.

Horizontal chlorophyll *a* distribution in Anderson-Cue Lake was determined four times in 1968 from February to the end of May. These measurements were made only in surface water. No correlative production estimates were completed. As indicated in Figure VI-4 phytoplankton was unevenly distributed in surface water on all sampling periods. Chlorophyll *a* levels were always highest in the near-shore environment ranging from 6 to greater than 15 mg/m^3. On three occasions these occurred in the same extreme southern part of the lake. Causes for the plankton patchiness are likely a combination of wind effects and local areas of enrichment especially in the shallow water where animals visit for drinking. Two experiments for coliform distribution confirmed animal movement in the shallow water along the lake margin.

Limiting nutrients for phytoplankton growth were determined essentially using Goldman's technique (1964, 1965) for bioassay. Many results using this method are varied and interpretation is difficult to make. Generally three qualitative judgements can be made. A particular substance may be limiting to plant growth, result in no change or elicit an inhibitory response. The results of these bioassays are shown in Table VI-5. Considering Anderson-Cue Lake, phosphorus limited primary production 92 percent of the time during 1967 trials. The phytoplankton did not respond to nitrogen additions indicating that this substance was not a limiting growth factor.

Verification of the nitrogen experiments has been carried out using a laboratory technique proposed by Fitzgerald (1968). The procedure essentially employs an exposure of ammonia nitrogen to a population of organisms and ammonia uptake is followed over a set time period. The results from this procedure (Table VI-6) showed that the natural plankton from Anderson-Cue Lake were not nitrogen deficient. These data reflect the rising ammonia levels in the experimental lake as nutrient enrichment progresses (see Section V).

The reasons why phosphorus concentrations in the water do not reflect those added to the lake are obscure. Certainly the supply is insufficient for the optimum growth of much of the phytoplankton. Phosphorus loss may be to the sediments although we have been unable to determine this as yet.

Substances other than N and P appear to be limiting during various times of the year. However, the difficulties encountered with this particular method make refined judgements questionable. A reliable standardized algal growth potential procedure is badly needed at this time for all those doing eutrophication research.

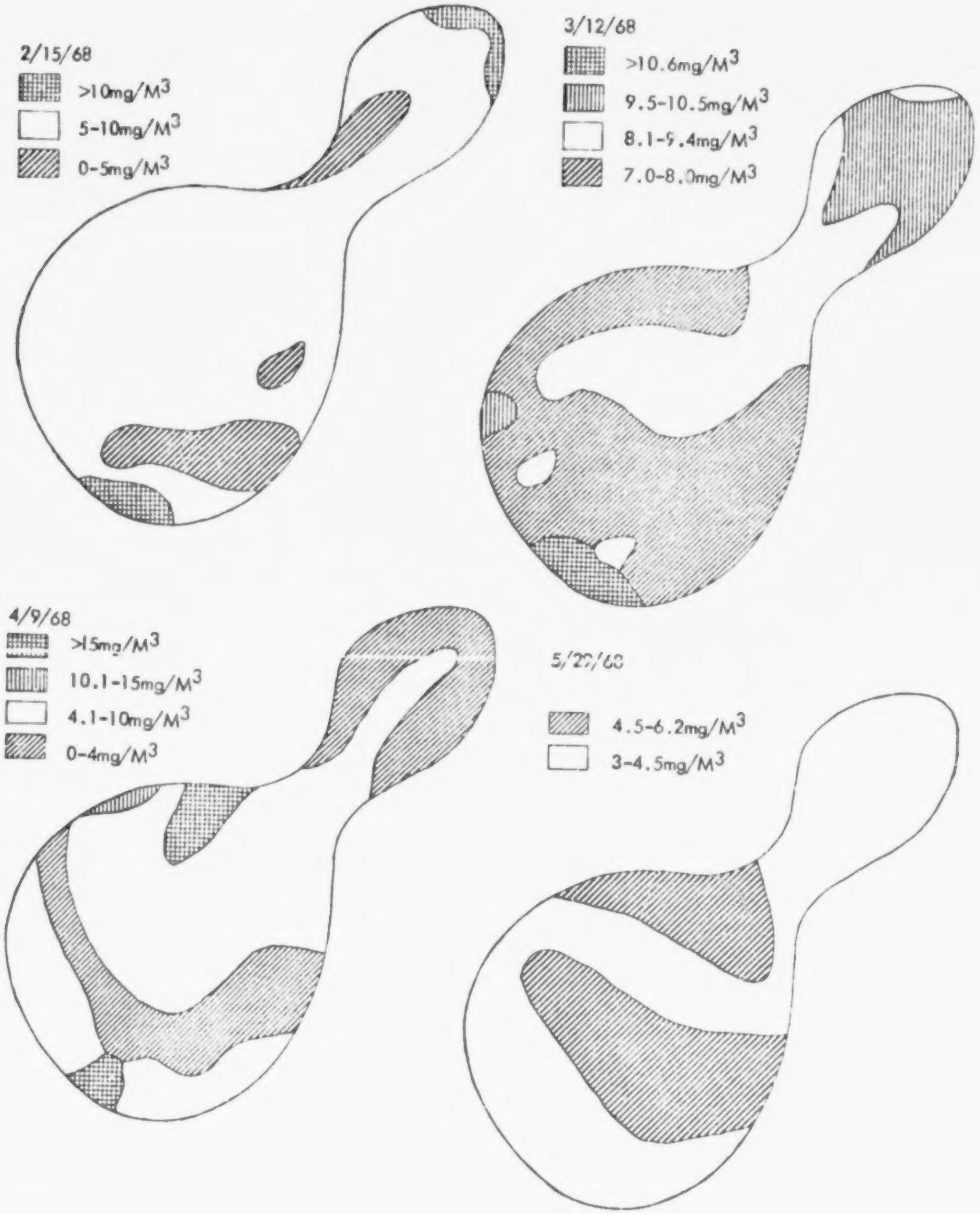

2/15/68
>10mg/M3
5-10mg/M3
0-5mg/M3
3/12/68
>10.6mg/M3
9.5-10.5mg/M3
8.1-9.4mg/M3
7.0-8.0mg/M3
4/9/68
>15mg/M3
10.1-15mg/M3
4.1-10mg/M3
0-4mg/M3
5/29/68
4.5-6.2mg/M3
3-4.5mg/M3

Figure VI-4. Horizontal Distribution of Chlorophyll a Anderson-Cue Lake.

TABLE VI-5

ALGAL GROWTH RESPONSE TO NUTRIENTS

Anderson-Cue Lake 1967

	1/4	1/24	3/14	3/28	4/11	5/23	6/6	6/20	8/1	8/29	9/12
N	-	-	-	X	X	-	-	-	-	-	-
P	+	+	+	-	+	+	+	+	+	+	+
N,P		+	+						+	+	+
Fe	X	+	X	X	X		-	-	-	-	-
Si		X		+	X		-	-	-	X	X
S	-	-		X	-	-	-	-	X	X	X
Vitamins	-	-		-	-		-	-	X	-	-
Trace Metals	-	-		X	X		X	-	-	-	-
EDTA	X	-		-	-		X	-	-	-	-

McCloud Lake 1967

	2/14	3/14	3/28	4/11	6/6	6/20	8/1	8/29	9/12
N	-	X	-	-	-	-	-	-	-
P	+	X	X	X	-	-	+	-	+
N,P	+	X					+	-	-
Fe	-	+	-	+	-	-	-	X	X
Si	+		+	-	+	-	X	-	+
S	-	+	+	+	-	-	X	+	+
Vitamins	-		-	-	-	-	X	+	+
Trace Metals	+	+	-	-	+	-	X	+	+
EDTA	-	+	-	+	+	X	X	-	+

+ = Limiting

X = Inhibitory

- = No Change

TABLE VI-6

AMMONIA UPTAKE BY ALGAE IN ANDERSON-CUE WATER

Time (min.)	Chlorella[1]	Filamentous Chlorophyceae[2]
0	1.24*	0.83*
+15	1.30	0.81
+30	1.35	0.84
+45	1.36	0.92
+60	1.38	0.89
+90	----	0.97

[1] laboratory stock culture

[2] filamentous green algae
probably Mougeotia collected in Anderson-Cue Lake.

*NH_4-N mg/1

Figure VI-5 shows the results of phosphorus addition to natural phytoplankton in Anderson-Cue water over a period of 120 hours. The experiment was carried out to determine lag time in phosphorus uptake by phytoplankton. It may be seen that maximum stimulation of algae by phosphorus as detected by labeled C-14 carbonate fixation occurs in 72 hours.

This particular time dependent bioassay method is very useful as a tool which can be used to follow the enrichment of single lakes by observing the change in slope of the response line at successive time periods. In addition comparative relationships among lakes within a region can be made. As can be seen from Figure VI-5 the greatest demand for phosphorus occurs during the summer in Anderson-Cue Lake and decreases considerably during the fall when biological activity is lower. Uptake of P in McCloud Lake is lower than Anderson-Cue and probably is due to a lower biomass of plankton organisms. Maximum uptake by organisms in the control lake occurs in 48 hours.

Goldman (1965) has noted photosynthetic stimulation from the addition of various compounds and elements in trace quantities. Lakes showing micronutrient deficiencies frequently can be found and such substances as vitamins and various cations doubtless play an important role in algal growth cycles. Sources of these materials are provided to lakes by (1) tributary streams, (2) runoff from land, or (3) interchange from sediments. Lakes near urban centers could very well receive some micronutrients from rain falling through polluted air.

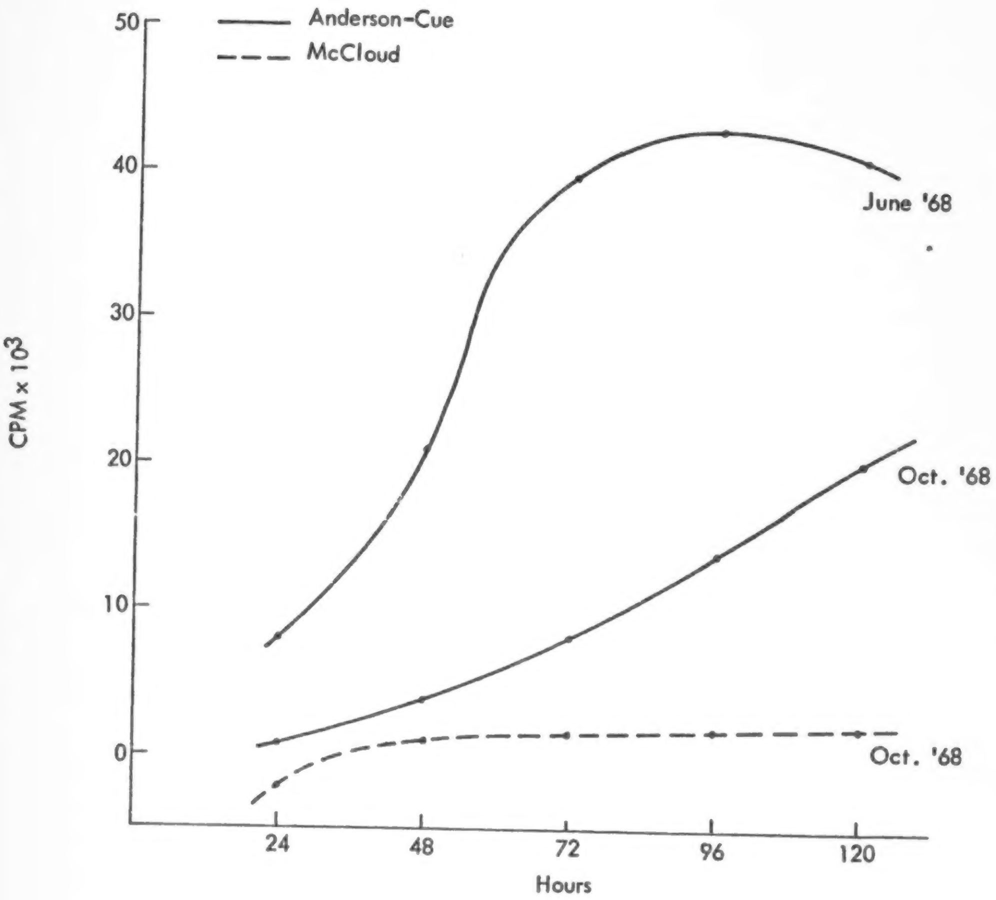


Figure VI-5 Carbon - 14 Fixation by Phytoplankton Stimulated with 100μgm Phosphorus.

Bioassay data on the two lakes show that cations limited algal photosynthesis in trials carried out on McCloud Lake. No similar pattern was observed in Anderson-Cue Lake during the same period. Two times during the study vitamin additions stimulated algal growth in McCloud Lake with no correlative response in Anderson-Cue water. It seems unlikely that differences between the two lakes could be attributable to variation in nutrient loading since enriched sewage effluent was not added to Anderson-Cue Lake until March, 1967. Therefore, at the present time differences in algal growth response to micronutrients appear to be inherent between the two lakes.

Characteristics of Littoral Zone

Littoral plant growth as expressed in dry weight has remained constant in both lakes. Since this area experienced an extended drought during the winter and early spring months of the year 1967-1968, both lakes dropped considerably, exposing former submerged stations. Those stations out of water were not cut in December. A second problem encountered was that of migrant cows feeding in these areas. Adequate fencing now prevents this from occurring. Table VI-7 contains the results of this part of the project. As might be expected plant growth was greatest during the spring and summer months and least in the fall and winter. Average dry weight per square meter of littoral growth in Anderson-Cue Lake amounted to 50 grams which represented an increase from 1967 of 20 grams/m^2. Nutrients added to the lake expectedly would enhance the growth of marginal vegetation, but it is too soon to say that the 1968 data reflect the influence of induced eutrophication.

The vegetation of the two lakes was studied to determine the kinds of plants, and the density and growth features of these plants in the littoral zones. McCloud Lake was studied to find contrasts, if any, between it, without pollution, and Anderson-Cue Lake with well recorded pollution.

As mentioned earlier, both of the lakes decreased in depth and size in 1967-1968, and the receding waters left a wide zone where formerly water flooded the shore. In both cases, the littoral was generally divided into three zones as far as the kinds of plants and vegetation were concerned. These were: (1) The Upper Zone with some shrubs present or evidence that they were formerly present; (2) The Middle Zone where grasses, sedges, and other herbs are abundant, but very few of the true aquatic plants occur; and (3) The Lower Zone where distinctly hydrophytic herbs and some aquatic plants occur. This Lower Zone has, due to the receding water, a number of the plants usually common in open water, such as the water lilies and the maidencane grass.

These three zones around McCloud Lake were more distinct and had a denser population of plants than around Anderson-Cue Lake. Except for the Lower Zone near the water the same species of abundant plants were

Table VI-7

STANDING CROP ESTIMATES OF ANDERSON-CUE AND McCLOUD LAKES

Station	Plant Dry Wt. (g)	Plant Ash Wt. (g)	Organic Matter	% Organic Matter
March - May, 1967				
Anderson-Cue				
1	17.5749	4.1382	13.4367	76.4
3	12.2894	0.8118	11.4776	93.4
5	18.9235	4.4170	14.5065	76.7
6	44.3655	5.2483	39.1172	88.2
7	5.2773	1.3142	3.9631	75.1
McCloud				
1	11.9673	0.7494	11.2179	93.7
2	55.4363	7.7995	47.6368	85.9
3	31.0443	1.6050	29.4393	94.8
June - August, 1967				
Anderson-Cue				
1	36.6874	3.9242	32.7632	89.3
2	22.0299	2.0512	19.9787	90.7
3	19.3535	2.5064	16.8471	87.0
5	105.7579	6.6955	99.0624	93.7
7	39.8170	2.3864	37.4306	94.0
McCloud				
1	21.3215	2.8341	18.4874	86.7
2	27.0365	1.2425	25.7940	95.4
3	50.8171	3.9842	46.8329	92.0
October - December, 1967				
Anderson-Cue				
1	0.6651	0.0773	0.5878	88.4
2	5.0363	0.7867	4.2496	84.4
3	7.7053	2.0148	5.6905	73.8
6	10.1398	2.0935	8.0463	79.4
McCloud				
1	3.6714	0.6179	3.0535	83.2
January - March, 1968				
Anderson-Cue				
1	1.3599	0.2388	1.1211	82.4
2	2.8250	0.6043	2.2207	78.6
3	2.0906	0.2597	1.8309	87.6
5	5.9957	1.0297	4.9662	82.8
6	0.7454	0.1124	0.6330	84.9
7	2.2399	0.2808	1.9591	87.5
January - March, 1968				
McCloud				
1	1.7174	0.3277	1.3897	80.9
2	1.9834	0.1669	1.8165	91.6
3	1.2515	0.1402	1.1113	88.8
April - June, 1968				
Anderson-Cue				
1	44.5779	9.0419	35.5360	79.7
2	24.8772	6.4809	18.3963	74.0
3	21.4956	4.8200	16.6756	77.6
5	83.6573	9.7295	73.9278	88.4
6	36.9836	12.0098	24.9738	67.5
7	38.1837	13.8765	24.3072	63.7
McCloud				
1	43.7322	5.9879	37.7443	86.3
2	23.5226	3.7630	19.7596	84.0
3	41.6614	8.6337	33.0277	79.3
Summary - March 1967 - March 1968				
Anderson-Cue				
1	56.2873	8.3785	47.9088	85.1
2	29.8912	3.4422	26.4490	88.5
3	41.4388	5.5927	35.8461	86.5
5	130.6771	12.1422	118.5351	90.7
6	55.2507	7.4542	47.7965	86.5
7	47.3342	3.9814	43.3528	91.6
McCloud				
1	38.6776	4.5291	34.1485	88.3
2	84.4562	9.2089	75.2473	89.1
3	83.1129	5.7294	77.3835	93.1

present in both littoral belts. The notable difference was an obvious decrease in density and the number of kinds of plants present in the Lower Zone along the waters edge of Anderson-Cue Lake, as compared to McCloud Lake and to the density of plants in the Middle Zone of Anderson-Cue Lake. This part of the Lower Zone that shows injury and death of some of the Lower Zone plants is especially notable because some of the plant species were not injured by what is presumed to be the toxic effects of the pollution and there are a few, such as Ludwegia alternifolia, which were only abundant in this "polluted zone".

The following is a brief and general list of the plants in each of these three littoral zones, and also a list to show the plants of the Lower Zone of Anderson-Cue Lake which died or became less abundant.

GENERAL PLANT COMPOSITION OF LITTORAL ZONES
McCloud and Anderson-Cue Lakes

Upper Zone

- Hypericum fascilculatum
- Cephalanthus occidentalis
- Spartina bakerii
- Andropogon spp.
- Pluchea sp.
- Eupatorium capillifolium
- Juncus effusus
- and other upland herbs

Middle Zone

- Sabatia campanulata
- Lachnocaulon minus
- Pluchea foetida
- Fuirena breviseta
- Juncus sp.
- Manisuris tuberculosa
- Cyperus spp.
- Xyris pallescens
- Lachnocaulon sp.
- Panicum hemitomon, and many other grasses and herbs
- Most of these do not stand flooding

Lower Zone

- Webateria (proliferating sedge, very small)
- Sagittaria graminea
- Fuirena spp.
- Erioaulon compressum
- Utricularia subulata
- Utricularia cornuta
- Cyperus spp.

Lower Zone Cont.

- Lachnocaulon minus
- Sabatia campanulata
- Lycopodium spp.
- Xyris pallescens
- Panicum hemitomon
- Leersia sp.
- Ludwegia alternifolia
- Cephalanthus occidentalis (small)

CHANGES IN "POLLUTED PART" OF LOWER ZONE

Plants that seem definitely killed or reduced in size and number

- Sagittaria graminea
- Lachnocaulon minus
- Xyris pallescens
- Sabatia campanulata
- Lycopodium spp.
- Fuirena spp.
- and some of the Utricularia sp.

Plants that survived, and in some areas seem to grow better in the "polluted part" of this Lower Zone.

- Websteria sp.
- Leersia sp.
- Utricularia sp.
- Panicum hemitomon
- Ludwegia alternifolia

Of these, the Ludwegia seems to grow taller and denser.

This "polluted" part of the Lower Zone is widest, about 5-7 feet along the southwest shore of Anderson-Cue Lake. It is narrower along the northeast part of this lake, being about 2-4 feet wide. The differences in width of the probably polluted zone may be due to more prevailing winds that make higher water in the Southwest shore area. This shore vegetation needs to be studied more intensely to find causes and extent of this death of plants. Similar surveys of the kinds of plants and vegetation zones should be made 3-4 times a year.

Provisional Algal Assay Procedure (PAAP)

In the laboratory, preparation was made to adapt the provisional algal assay procedure (PAAP), as proposed by the FWPCA's Joint Industry/Government Task Force on Eutrophication. All three of the recommended assay organisms are growing on a lighted shaker table at 24°C. Up to this time, *Selenastrum capricornutum* has been used as the experimental organism. The other two organisms, *Microcystis aeruginosa* and *Anabaena flos-aquae*, will be similarly tested.

Five methods of assaying algal growth are being evaluated. These include cell count, radiocarbon uptake, dry weight, light absorbance, and adenosine triphosphate (ATP) level. Of these methods, absorbance and radiocarbon uptake are best suited for quantifying Selenastrum growth. Dry weight and ATP determinations are not sensitive enough using the inoculum size presecribed. Water samples from an unproductive and a productive lake have been subjected to the PAAP. The results obtained were as expected i.e., the test organism grew faster and reached higher numbers in the productive lake water than in the unproductive lake water. Further tests of this nature are now being conducted, using several different lakes as well as sewage treatment plant effluent.

Laboratory work on the PAAP study is being done routinely. To date, all four of the methods of growth analysis outlined in the procedure have been tested with all three organisms. We have found only two of these methods, cell counting and absorbance measurements, to be reliable as tools for assaying growth because this study involves working with cultures of low cell number. However, another method, chlorophyll a (Creitz and Richards, 1955), has been tried and found to be sensitive enough to estimate growth at these low cell numbers. The possible use of the Coulter Counter instead of the S-R cell to increase the precision of cell counting is planned. Having established the assay methods, experimental work with lake water and lake sediment will be continued and enhanced.

Preliminary tests using sediment collected from Anderson-Cue Lake and inoculated with the organism Selenastrum demonstrated a significant difference in the growth rates of the organisms in flasks containing PAAP media plus sediment leached water versus PAAP media only. Increasing the volume of sediment leached water added to each culture flask did not increase the growth rate.

Extractive phosphate and alkaline phosphatase. Both parameters were measured in the apical portions of the littoral vegetation as well as attached filamentous chlorophyceae. Table VI-8 presents some preliminary data. The data obtained thus far would indicate the growth to be limited by the lack of available phosphorus.

Secondary and Tertiary Trophic Levels

The research bearing on the determination of secondary and tertiary trophic levels in both lakes has involved work with zooplankton and the planktivorous brook silverside (Labidesthes sicculus). This fish is a significant element in the ecosystem of both Anderson-Cue and McCloud Lakes feeding chiefly in pelagic areas on zooplankton and small insects. It is very selective in what it eats, the size of the prey being definitely correlated with fish size. Juvenile Labidesthes feed

TABLE VI-8

EXTRACTIVE PHOSPHATE AND ALKALINE PHOSPHATASE

Plant	Extractive Phosphate mg P/100 mg dry wt.	Alkaline Phosphatase Units/mg/hr
Mougeotia (outfall)	0.17	300.
Mougeotia (N.E. end)	0.01	60.
Ludwegia	0.10	16.
Websteria	0.03	16.
St. Johns Wort	0.04	3.
Utricularia	0.02	9.
Mayaca	0.01	7.

chiefly on rotifers and copepod nauplii while larger individuals eat cladocera, adult copepods and occasional small insects. (Table VI-9 represents a partial spectrum of zooplankton ingested by Labidesthes based on examination of gut contents). Labidesthes reproduce in spring and early summer and few individuals live longer than a year, so the food requirements of the population will change from summer to winter as the fish grow. Thus the food availability is related not so much to the total biomass of zooplankton as to the biomass of acceptable food items during a given season. The delicate balance involved will be expected to change as the lake becomes more eutrophic.

Zooplankton samples have been collected bi-weekly with a tow net and microscopic counts have been made according to Standard Methods for the Examination of Water and Wastewater (1965). Individuals of each important species were picked out under a dissecting microscope, dried in a vacuum desiccator and weighed on a calibrated quartz helix (Table VI-10). In order to get an adequate deflection of the helix, groups of 5-200 individuals are weighed at a time and an average mass calculated. Average mass per individual can be multiplied by number per square meter of lake surface to obtain the biomass of the organism in gm/m^2. Caloric values for species of zooplankters are determined using a microbomb calorimeter. Thus several years of bi-weekly data on zooplankton populations can be readily converted into biomass or energy content.

Data for conversion of zooplankton numbers to biomass can be found in Appendix F. Not all data are as yet available for conversion of zooplankton numbers to biomass. The accompanying Tables VI-11 and VI-12, showing the results from August 1967 and 1968, are examples of the type of information which are available for each month of the investigation. Additional population densities (No./m^2) for 1967 and 1968 are presented in Vol. II, Table 2-9, Appendix F.

TABLE VI-9

FOOD OF *LABIDESTHES SICCULUS*

Labidesthes Standard length 19 mm Approximate dry weight 10 mg

Gut Contents	Number	Weight (μg)
Bosmina	19	22.5
Tropocyclops	7	3.5
Larval Copepods	11	1.6
Chydorus	4	4.8

Total weight
(dry) of food.
32.4 μg

Labidesthes Standard length 29 mm Approximate dry weight 23 mg

Gut Contents	Number	Weight (μg)
Bosmina	30	35.5
Small Cyclops	113	56.8
Larval Copepods	27	3.9
Chydorus	2	2.4
Diaptomus	1	3.6
Diptera	1	45.0

Total weight
(dry) of food.
147 μg

Labidesthes Standard length 37 mm Approximate dry weight 49 mg

Gut Contents	Number	Weight (μg)
Bosmina	14	16.5
Small Cyclops	30	15.1
Larval Copepods	3	0.4
Diaptomus	14	50.4
Daphnia	8	31.4
Diaphanosoma	1	1.4

Total weight
(dry) of food.
115 μg

TABLE VI-10

DETERMINATION OF ZOOPLANKTON WEIGHTS IN ANDERSON-CUE AND McCLOUD LAKES

Organism	No. of Determinations	Total Individuals	Range Dry Weight (micrograms)	Avg. Dry Weight (micrograms)
Keratella	4	320	0.036-0.053	0.0435
Larval Copepods	2	200	0.145-0.148	0.146
Tropocyclops	5	125	0.371-0.608	0.503
Bosmina	5	97	0.73-1.38	1.182
Diaphanosoma	6	110	0.872-1.82	1.423
Diaptomus	10	100	3.11-4.53	3.603
Daphnia	7	70	1.49-5.77	3.922
Holopedium	2	18	4.5-6.6	5.549
Mesocyclops	10	95	4.81-10.8	8.47
Chaoborus	5	35	14.7-84.6	45.6

Weights in this table were obtained by weighing groups of from 5-200 individuals of each species on a calibrated quartz helix.

TABLE VI-11

ZOOPLANKTON DENSITIES AND CALCULATED BIOMASS
FOR AUGUST 1967

Anderson-Cue Lake

	3 Aug.		11 Aug.		26 Aug.	
	No/m^2	mg/m^2	No/m^2	mg/m^2	No/m^2	mg/m^2
Tropocyclops	4,715	2.372	2,160	1.086	19,742	9.930
Mesocyclops	3,169	26.841	1,452	12.298	13,271	112.405
Diaptomus	11,038	39.770	5,179	18.660	22,484	81.010
Larval Copepods	18,987	2.772	27,836	4.064	74,147	10.825
Bosmina	1,227	1.450	5,706	6.744	18,050	21.335
Daphnia	3,156	12.378	3,876	15.202	761	2.984
Diaphanosoma	879	1.251	0	0.0	0	0.0
Holopedium	0	0.0	0	0.0	0	0.0
Keratella	9,922	0.432	9,065	0.394	26,699	1.161
Total		87.266		58.448		239.650

Avg. Biomass (mg/m^2) 128.45

McCloud Lake

Cyclops (sp. 1)	5,625	2.829	5,371	2.702
Cyclops (sp. 2)	3,781	32.025	3,611	30.585
Diaptomus	9,628	34.690	8,713	31.393
Larval Copepods	36,030	5.260	47,800	6.979
Bosmina	6,503	7.688	10,540	12.458
Daphnia	105	0.412	79	0.310
Diaphanosoma	367	0.522	26	0.037
Holopedium	0	0.0	0	0.0
Keratella	41,370	1.800	66,190	2.879
Total		85.226		87.343

Avg. Biomass (mg/m^2) 86.28

TABLE VI-12

ZOOPLANKTON DENSITIES AND CALCULATED BIOMASS FOR AUGUST 1968

Anderson-Cue Lake

	12 Aug.		19 Aug.		26 Aug.	
	No/m^2	mg/m^2	No/m^2	mg/m^2	No/m^2	mg/m^2
Cyclops (sp. 1)	24,200	12.173	34,496	17.351	43,847	22.055
Cyclops (sp. 2)	7,991	67.684	16,666	141.161	44,385	375.941
Diaptomus	144,514	520.684	92,690	333.962	291,058	1048.682
Larval Copepods	192,000	28.032	90,635	13.233	194,756	28.434
Bosmina	1,142	1.350	685	0.810	7,801	9.221
Daphnia	228	0.894	228	0.894	807	3.165
Diaphanosoma	0	0.0	228	0.324	4,035	5.742
Holopedium	0	0.0	0	0.0	0	0.0
Keratella	58,901	2.562	42,464	1.847	538	0.023
Total		633.379		509.583		1493.263

Avg. Biomass 878.74 mg/m^2

McCloud Lake

Cyclops (sp. 1)	36,528	18.374	23,743	11.943	27,976	14.072
Cyclops (sp. 2)	11,187	94.754	19,405	164.360	28,514	241.514
Diaptomus	25,570	92.129	34,702	125.031	91,998	331.469
Larval Copepods	86,982	12.699	101,137	14.766	80,162	11.704
Bosmina	27,168	32.113	24,656	29.143	112,980	135.542
Daphnia	1,142	4.479	0	0.0	0	0.0
Diaphanosoma	12,785	18.193	20,775	29.563	35,625	50.694
Holopedium	228	1.265	0	0.0	0	0.0
Keratella	2,511	0.109	1,826	0.079	0	0.0
Total		274.115		374.885		784.995

Avg. Biomass 478.00 mg/m^2

Populations of many zooplankton species have shown tremendous fluctuations over the time period of the study. Some of these fluctuations are seasonal in nature or weather-induced but others may be correlated with changing physio-chemical parameters of the lake. Definite trends caused by increased enrichment have not yet been established.

The change in L. sicculus population in Anderson-Cue Lake has been very spectacular. The population has dropped from an estimated 130,000 in November, 1967, to virtually zero at present. The McCloud population has shown no corresponding decline.

L. sicculus has previously been shown to be very susceptible to high turbidities often accompanying pollution, but Anderson-Cue turbidities have not risen nearly as high as those in some local lakes where L. sicculus is abundant. Possibly the decline was caused by the extremely low water level and concomitant lack of littoral vegetation suitable for spawning.

Table VI-13 contains a partial faunal list from the study lakes. This information was provided by Paul and Karolyn Maslin whose research dealing with secondary and tertiary production levels formed the basis for two dissertations reproduced in Vol. II as Appendix A and B. Investigations of this kind are very important as virtually no information is available for the southeast U.S. regarding zooplankton species diversity, production rates and changes in species composition as influenced by the eutrophication process. The most significant conclusions drawn from these works are described below.

Equilibrium between zooplankton and environment. Slobodkin (1954) demonstrated that a fairly long time period, on the order of 40 days, is required for a single cladoceran species, Daphnia obtusa, to reach an equilibrium population is a constant laboratory environment and has suggested that natural populations may never reach equilibrium before further environmental changes occur. In the light of the present study several additions may be made to Slobodkin's hypothesis. First, in a mixed culture or natural community the environment of any one species includes all of the other species as well as the physical parameters. If some environmental change occurs, all populations will tend to adjust to the new conditions. The adjustment is not instantaneous but requires a time period of at least one and probably several generations. As any one species population changes in adjustment to the environment it will automatically alter the environments of all other species. Thus the time required for a community to equilibrate is greatly extended. If other changes should occur before equilibrium is reached, the community will be in perpetual nonequilibrium. Forces will always be present pushing the populations toward equilibrium, but equilibrium can never be attained, since the equilibrial size of any population will be constantly changing.

TABLE VI-13

A PARTIAL FAUNAL LIST FROM LAKES ANDERSON-CUE AND McCLOUD

FISHES:

Chaenobryttus gulosus
Etheostoma fusiforme
Fundulus chrysotus*
Fundulus lineolatus*
Gambusia affinis
Heterandria formosa
Labidesthes sicculus
Lepomis macrochirus
Micropterus salmoides

LIMNETIC CLADOCTERA:

Bosmina coregoni
Daphnia ambigua
Diaphanosoma brachyurum
Holopedium amazonicum

LITTORAL CLADOCERA:

Acroperus harpae
Acantholeberis curvirostris
Alona affinis
A. costata
A. guttata
A. quadrangularis
Alonella globulosa
Anchistropus minor*
Camptocercus rectirostris
Ceriodaphnia pulchella
Chydorus biocornutus*
C. piger
C. sphaericus
Eurycercus lamellatus*
Graptoleberis testudinata
Ilyocryptus spinifer
Macrothrix rosea
Monospilus dispar
Pleuroxus sp. (Hastatus?)
Simocephalus expinosus*

*indicates species found only in Lake McCloud

LIMNETIC COPEPODS:

Diaptomus floridanus
Cyclops bicuspidatus
Tropolyclops prasinus

LITTORAL COPEPODS:

Cyclops exilis
Eucyclops speratus

LIMNETIC ROTIFERS:

Conochiloides sp.
Conochilus sp.
Keratella americana (?)
K. taurocephala
Pedalia sp.
Polyarthra sp.

LITTORAL ROTIFERS:

Brachionus sp.
Keratella serrulata
Lecane spp.
Macrochaetus sp.
Monommata sp.
Monostyla sp.
Trichocerca spp.

Demonstration of cause-effect relationships between environmental variables and population size or group biomass is difficult because of the nonequilibrial nature of the relationship, as well as the lag response described by Slobodkin (1954) and Edmondson (1965). The lag period necessary for any species population to adjust to an environmental change is dependent upon temperature and food (Ingle, _et al_, 1937; Hazelwood and Parker, 1961; Elbourne, 1966). Accordingly, no two species can be expected to have the same lag time, and lag time for any one species will not be constant. Even if variations in a single environmental factor are responsible for changes in zooplankton biomass, correlation of biomass with the particular factor may be poor. Comparison of taxonomic groups, or even separate species, with environmental factors should give truer correlations but even these will be blurred by variations in time lag with environmental changes.

Competition patterns of zooplankton species. The correlation coefficients between populations of the different cladocera showed no tendency for any species to decline while any other species was increasing. On the contrary, some showed positive correlations (_D. ambigua_ to _H. amazonicum_; _B. coregoni_ to _D. brachyurum_). The pattern of dominance in cladocera, however, showed that a given set of environmental conditions might be distinctly more favorable to one species than to another. Even though two species were positively correlated, dominance of one over the other at a given time was almost certain. In the summer of 1968 in Anderson-Cue, all cladocera disappeared from the lake for a short time. As they began to come back, three species were seen. _B. coregonia_ and _D. ambigua_ appeared together, with both populations increasing rapidly but _Bosmina_ increased more rapidly than _Daphnia_, exceeding it in numbers by an order of magnitude as both populations began to level off. _D. brachyurum_ appeared about two weeks later than the other two but multiplied at a rate nearly equivalent to _Bosmina_'s initial rate and soon achieved a population roughly equal to _Bosmina_. The _Bosmina_ population then decreased by about an order of magnitude while _Diaphanosoma_ decreased only slightly, thus acquiring dominance.

The above example shows two things. First, competition probably exists between these species. Second, the effects of competition can be obscured by changes in the environment. When cladocera started to come back into the system all three were favored, just as populations of two or more species inoculated into a new medium would increase initially before competition became important. After the populations reached a "normal" level a distinct tendency for one to dominate was displayed.

Food-predator-climate relationships. The presence of competition but not competitive exclusion is explained by the non-equilibrium nature of the ecosystem. If an equilibrium is reached, the outcompeted species will be eliminated, but environmental changes effectively give the losing species a new start. If the environment is sufficiently transitory, species which would compete strongly in a laboratory culture may show a distinctly positive correlation. In the event that biological equilibrium should be reached, causing exclusion of some species, nearly all fresh-water plankters have some sort of resting stage which allows them to develop a new population at a later time (Hutchinson, 1967).

The smaller coefficients of variation for groups as compared to species and the better interlake correlation of total and group biomass as compared to species biomass indicate that factors acting to control the populations are acting on the whole trophic level rather than on individual species. The good correlation (r = 0.686) between zooplankton biomass in the two lakes indicates that climatic factors (i.e., factors which would affect both lakes) play a large part in regulating zooplankton populations, but the mechanism for action of climate on zooplankton is not intuitively obvious.

While the summer decline was statistically significant in both lakes, the reason it occurred is less easily demonstrated. When the summer data were ignored the zooplankton biomass followed the temperature curve. A possible explanation for the summer drop would be that temperature had passed the optimum for species present. However, zooplankton biomass returned to normal and, indeed, to its highest value while temperature was still above the level of the initial drop. Also the recovery from the summer low began while temperature was at maximum. The summer low could not be due to lack of food because both primary productivity and chlorophyll concentration of phytoplankton were higher during the summer.

A study of the reactions of individual species to the summer discontinuity provides an insight into its cause. Only the larger zooplankters showed a significant decline during the summer. Intermediate species showed essentially no response, while very small species such as the rotifers increased significantly. Also, rarer species of rotifers were much more likely to be seen during the summer biomass low. A further clue is provided by the fact that larval copepods did not decline; they even increased slightly. Evidently conditions were favorable for copepod reproduction since fewer adults were able to produce as many or more young. Accordingly the decline in adults must have been due to an increased death rate. This in turn points to an increased predation rate in summer with apparent selection for the larger forms producing results similar to those described by Brooks and Dodson (1965).

An explanation for increased predation during summer is readily available: Labidesthes sicculus and Lepomis macrochirus are spawning and the young of both are much more dependent upon zooplankton than are the adults. Hubbs (1921) and Werner (1969) have discussed the migration of fry of these species into the limnetic zone where they feed upon zooplankton, particularly microcrustacea. McLane (1955) reported that in Florida *L. sicculus* spawns throughout the summer while *L. macrochirus* spawns from May to October with most intensive spawning in June. Since the bluegill fry spend ca. 1.5 months in the limnetic zone (Werner, 1969), their period of heaviest predation falls exactly during the summer zooplankton low. The briefer summer decline in Anderson-Cue, 1968, as opposed to 1967 or McCloud, 1968, also supports the predation mechanism; the *L. sicculus* population in Anderson-Cue, 1968, for some unknown reason, was very much reduced by comparison with the 1967 population or the McCloud population.

When the period of summer decline is ignored, total zooplankton biomass is closely correlated with both temperature and primary productivity. Since temperature and primary productivity are strongly correlated throughout the year, it seems reasonable that the influence of climate on zooplankton biomass, as evidenced by the close correlation between lakes, is due to two principal factors, neither of which acts directly on the zooplankton. (1) Temperature limits primary production (given a reasonably constant nutrient supply), thus limiting the food available to zooplankton and, accordingly, the zooplankton during most of the year. (2) The onset of fish reproduction, with its concomitant predation surge, is determined by climatic factors, such as temperature and photoperiod, and thus is synchronized in both lakes.

In these lakes zooplankton as a group is food-limited during most of the year. During that period competition for food should be important. In the summer, however, when zooplankton biomass is at its lowest and primary productivity is at its highest, no competition for food should exist. Thus the summer is the period when the rotifers, relatively predation immune due to their small size, develop their largest populations. Also several rarer species of rotifers are much more common during the summer. Their apparent relationship to temperature merely reflects their reaction to the decreased competition during the summer. The same general explanation pertains to the change in frequency of *Daphnia* and *Bosmina* dominance with warm temperatures. Temperature is not directly involved; *Daphnia*, being larger, receives greater predation pressure than *Bosmina*.

Secondary production estimates. The estimations of secondary production and efficiency are, admittedly, very rough. The range from minimum to maximum estimate covers about an order of magnitude. However, the ranges for the 1968 values are reduced from that for 1967, probably reflecting the greater accuracy obtained with more frequent sampling. The range of efficiencies determined includes from a reasonably low efficiency to one impossibly high. The efficiencies associated with the "best estimate" are in line with the general ecology efficiency of 8-12 percent (Slobodkin, 1968).

An advantage of this method of estimating zooplankton production is that contributions made by each species or higher taxonomic group can be assessed. Thus in both Anderson-Cue and McCloud, 1968, copepods accounted for ca. 75 percent of the production, cladocera contributed ca. 24 percent, and rotifer species present coupled with their sporadic occurrence accounted for their low contribution to production.

There have been a few previous determinations of aquatic secondary production. As pointed out in the introduction, most of these were only rough estimates. The most important studies are summarized in Table VI-14. For comparative purposes all values are listed as originally reported and then as converted to kcal m^{-2} $year^{-1}$. Of the previous workers only McAllister reported any boundaries to production. The range of values from the present study is quite similar to that reported by McAllister and includes all of the other values for standing fresh waters. The "best estimate" of mean annual zooplankton production in Lakes Anderson-Cue and McCloud is ca. 50 kcal m^{-2}. As one would expect for oligotrophic lakes, this value lies toward the low side of the range for standing waters.

Zooplankton abundance factors. Of the environmental parameters examined, fluctuations in primary productivity and temperature had the greatest effect on littoral zooplankton abundance. This pattern was especially seen in cladocera and rotifera where primary productivity and temperature would be correlated with the rate of reproduction, and thus, changes in population densities of both groups.

In the multiple regression analyses copepoda were not highly correlated with the three environmental parameters. According to Hutchinson (1967), variations in copepod egg number are less clearly associated with environmental conditions than in cladocera. Also, the immature stages of the life cycle presumably give copepods a greater range of filtrable food, thus making them more adjustable to varying conditions than cladocera.

Both Anderson-Cue and McCloud had their highest density of cladocera in the summer, 1968, corresponding to high primary productivity. While both showed a decreased density in the fall, Anderson-Cue had a high density of cladocera from December through February and McCloud maintained low populations. This accompanied a high primary productivity.

Primary productivity in the two lakes was significantly correlated ($r = 0.511$, $p = 0.01$) in 1968-1969. However, in 1969-1970, this correlation was higher ($r= 0.907$, $p = 0.001$), indicating a greater similarity between the lakes.

TABLE VI-14

SOME REPRESENTATIVE RATES OF SECONDARY PRODUCTION IN AQUATIC ECOSYSTEMS

Investigator	Organisms	Ecosystem	Reported Rate	Converted to kcal $m^{-2}year^{-1}$
Odum and Yount (1954)	most herbivores	Silver Springs, Florida	240 g $m^{-2}year^{-1}$	1200
Stross, et al (1961)	crustacean zooplankton	bog lake	8 g $m^{-2}year^{-1}$	40
Straskraba (1963)	littoral zooplankton	fishpond	1.7 g N $m^{-2}year^{-1}$	53
Ilkowska, et al (1966)	limnetic zooplankton	two eutrophic lakes	27 and 40 g $m^{-2}year^{-1}$	135 and 200
McAllister (1969)	marine zooplankton	fertile area Pacific	1.5-23.2 g C m^{-2}year-1	15-232
Present study	limnetic zooplankton	oligotrophic lakes	4-52 g $m^{-2}year^{-1}$	20-260

In 1969-1970 both lakes again had high summer cladoceran populations and decreasing fall populations. Differences between cladoceran densities were probably due to an interaction between environmental parameters. Decreasing primary productivity and temperature and habitat changes due to increasing lake level resulted in a decrease in population density in both lakes in the fall. However, the greater abundance of C. sphaericus in McCloud than in Anderson-Cue from January through March, 1970, suggests that the better developed littoral zone of McCloud was not as strongly affected by lake level fluctuations. Benthic and vegetative inhabiting species had decreased population densities in both lakes.

Lake level. Fluctuations in lake level and the resultant effects on vegetation in the littoral zone had the greatest influence on species diversity. The general physical condition of sand lakes produces drastic changes in lake levels. During this study the above characteristic was observed. It may be expected that the variations found in the littoral zone, as affected by drought, would influence the species diversity. Since sampling depth was kept constant throughout the study, vegetation in the sampling area was reduced in the fall due to the rapid increase in lake level, slow macrophyte growth and delayed aufwuchs colonization. The continued increase in lake level might also have been responsible for the lower values of primary productivity in both lakes in the spring of 1970 compared to the spring of 1969. The pattern of species diversity was best related to the changes in lake level, since diversity was low as lake level increased and was high when lake level stabilized or was dropping. This would affect most chydoridae species since they are normal inhabitors of littoral vegetation. Exceptions may be found in those species either inhabiting the sediment water interface or the limnetic zone (A. quadrangularis and C. sphaericus).

Prey selection. Littoral cladocera were the most important food items for Etheostoma fusiforme and Heterandria formosa. When littoral cladocera were scarce E. fusiforme fed mainly on copepoda and nonplankton, while H. formosa chiefly ate rotifers. Food selection was determined by size and accessibility of prey. Cladocera were the most important items in the diet of both fishes. Energetically, this seems reasonable, since littoral cladocera are poor swimmers compared to copepods and would be easier to capture. Because of their small size, rotifers would be energetically important food sources only when numberous.

When cladocera were scarce, E. fusiforme consumed copepods and nonplankton, while H. formosa ate mainly rotifers and some nonplankton. Rotifers were a large component of the diet even when they were not abundant.

In Anderson-Cue *E. fusiforme* had a mean electivity index of -0.43 for copepods, while *H. formosa* had a value of -0.49. In McCloud the mean electivity index of *E. fusiforme* was +0.12 and that for *H. formosa* was -0.28. This implies that *E. fusiforme* was somewhat better at obtaining copepods than *H. formosa*, but they were not highly selected by either fish. Also *E. fusiforme* in McCloud was dependent on copepods for a longer time than in Anderson-Cue, due to the lower cladoceran populations.

As evident from the low levels of predation pressure (Table VI-15), the two fishes had an abundant food supply when cladocera were numerous. Because of partitioning of resources when cladocera were scarce, competition did not occur. The period when their feeding habits were most similar (when their niches overlapped) was when food supply was not limiting.

Prey selection appeared to be determined by a combination of factors. Both fishes had high mean electivity indices for the same species of cladocera. These were generally large and/or benthic species. *E. fusiforme* always had higher indices for the smaller vegetative inhabiting species, but these were usually negative. Mean indices for *C. sphaericus* were similar, indicating an equal availability.

If the average percent of the diet made up by each cladoceran species is examined, the results are similar. The large benthic species averaged 5.0 percent of the diet of *E. fusiforme* and 2.4 percent of the diet of *H. formosa*. Small species which inhabit the vegetation constituted 0.9 percent of the diet of *E. fusiforme* and 1.6 percent of the diet of *H. formosa*. Thus, the large benthic species were more important to both fishes than the small vegetative inhabiting species.

Size and accessibility seemed to be equally important factors in food selection. Accessibility refers to the behavior of the prey, such as concealment or ease of escape. It also refers to characteristics of the predator which equip it for catching certain prey. This is similar to the definition of Ivlev (1961), although he considers accessibility to be more a property of the prey. To a slight extent, size is a component of accessibility, since larger plankters are usually better swimmers. Also, an organism may be too large or too small to be eaten. In this case all organisms studied were within a suitable size range for both fishes.

Large benthic cladocera were selected by both fishes over small species. However, since *E. fusiforme* rests on the bottom these cladocera may be more accessible, which would explain higher electivity indices. Among the rotifera and copepoda, accessibility seemed to be more important than size. *H. formosa* selected rotifera over copepoda, perhaps because it was not as efficient as *E. fusiforme* at catching copepods.

TABLE VI-15

Monthly Predation Pressure by E. fusiforme and H. formosa in Lakes Anderson-Cue (A-Q) and McCloud (McC), 1969-1970.

Organism		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
A. curvirostris	A-Q				+			0.24	+	+
	McC						+	0.68	0.025	
A. harpae	A-Q	0.05	0.05	0.10	+	+	0.11	0.59	0.62	0.17
	McC						+	+		
A. quadrangularis	A-Q	0.008	0.03	0.08	0.058	0.01	0.04	0.52	0.49	+
	McC	0.20	0.35	0.038	0.12	0.01	0.05	0.09	0.087	0.107
C. piger	A-Q		0.04	0.01			+			+
	McC	0.08	0.02	0.24	0.002	+	+	0.10	0.045	0.25
C. sphaericus	A-Q	0.08		0.09	0.19	0.49	0.36	0.82	3.56	0.13
	McC		+			0.43	0.37	0.20	0.05	0.36
G. testudinaria	A-Q	+	+	++	0.10	0.012	0.072	0.03	+	+
	McC		0.89				0.01	+	0.024	+
I. spinifer	A-Q	0.09	0.05	0.10						
	McC		+		0.008	+		0.044		
M. rosea	A-Q	0.12	0.64	++	0.25	++	+	+		
	McC		++		+			+		
P. striatus	A-Q	0.006	0.02		0.008	0.027	0.24	+	0.02	
	McC	+	0.03					0.02	0.014	+
S. exspinosus	A-Q	0.34	0.93	0.22	0.28	+	+			
	McC	0.03	0.17	+	+		+	0.24	+	+
Lecane spp.	A-Q	0.021	0.31	0.07	0.17	+	0.105			
	McC	0.52	0.21	0.10	0.17	0.01	0.12	0.05	0.014	0.016
Monostyla sp.	A-Q	0.08	0.054	0.08	0.41		0.007			
	McC	0.63	0.14	0.09	0.23		0.16	0.06	0.006	0.02
Copepoda	A-Q	0.04	0.05	0.04	0.03	0.033	0.006	0.03	0.01	0.007
	McC	0.05	0.16	0.003	0.024	0.016	0.03	0.04	0.018	0.032

+ = eaten, but not present in plankton sample.
++ = large quantity eaten, but not present in plankton sample.

Abundance, of course, plays some role. If an organism is so rare that it is seldom encountered, it would not seem to be energetically important. However, small cladocera constituted sizeable portions of the diet when scarce. Thus, abundance was not a significant factor in prey selection.

Predation pressure. The feeding of *E. fusiforme* and *H. formosa* on the littoral zooplankton is only a small part of the total predation. All of the littoral fishes feed to some extent on them. Also, species of game fish and pelagic fishes spend a portion of their lives in the littoral. Bluegill fry, in particular, feed heavily on littoral cladocera in these lakes (personal observations).

The values of predation pressure were usually low. The highest value was on *C. sphaericus*, 3.56 percent, in February, 1970. Dodson (1970) measured removal rates of Daphnia due to salamander and midge larvae predation in a similar fashion. When his values are expressed as percent removal per day, they are of the same order of magnitude as the values for *C. sphaericus* in this study. Hall (1964) estimated total predation pressure on *Daphnia* in the summer to be 21.9 percent per day. He concluded that predation was the most important factor controlling population size in the summer.

The fact that gut clearance rate increases with temperature and that fish densities are greatest in the summer indicates a greater predation in the summer, which corresponds to the time of highest number of species and abundance of littoral zooplankton. This strengthens the observation that the littoral zooplankton are not controlled by *E. fusiforme* and *H. formosa*. However, bluegill fry enter the littoral in late August from the limnetic zone. Since this is a time of decreasing zooplankton populations, they may exert a much stronger predation pressure.

The effect of predation on prey populations has been examined. Slobodkin (1961) speculated that where two species are limited by predation, they can coexist if they differ from each other ecologically to some significant degree. The stability of a system is increased by ecological diversification of the species. Connell (1961) found that predation tended to decrease competition between two species of barnacles. Paine (1966) suggested that animal species diversity is related to the number of predators in a system and their efficiency in preventing single species from monopolizing some limiting resource.

Since many species of littoral zooplankton are approximately the same size and utilize the same food supply, they would compete when these resources were limiting. By keeping prey species populations below the level of resource limitation, predation could play an important role in maintaining a high species diversity.

Eutrophication effects. It was difficult to demonstrate a cause-effect relationship between changes in littoral zooplankton and enrichment of Lake Anderson-Cue. Brooks (1969) mentioned that an increase in standing crop of herbivores was an expected consequence of enrichment. The total zooplankton was generally greater in Anderson-Cue than in McCloud. However, a decrease in abundance was seen in both lakes the second sampling year. Changes in abundance, species composition and diversity were more likely correlated with changes in the littoral zone as a result of lake level fluctuations than with enrichment.

Whiteside and Harmsworth (1967) found a high correlation between transparency and species diversity in Danish and Indiana lakes. Since chydorids are typically inhabitants of the macrophytic vegetation, they suggest that this habitat extends to greater depths in clearer lakes. Lesser penetration of light in more enriched lakes due to phytoplankton blooms and dissolved organic matter would decrease habitat diversity and thus, species diversity. Whiteside (1970) divided the chydorid associations into three areas: the littoral vegetational, the littoral benthonic and the limnetic. He found that in lakes of extreme eutrophy, limnetic species (*C. sphaericus*, *A. rectangula*) comprised most of the chydorids. The benthic species were not as much affected by eutrophication as those which inhabited the littoral vegetation.

Changes in habitat diversity can occur as a result of long-term phenomena, such as eutrophication, or short-term phenomena, such as lake level fluctuations. Both would have similar effects on diversity and density of littoral zooplankton. Also, changes in the composition of zooplankton may result from selective predation. In order to use littoral zooplankters as indicators of eutrophication, the effects of changes in environmental parameters, as well as selective predation, on the population dynamics of littoral zooplankters must be understood.

The effects of environmental variables on littoral zooplankton populations are complex. Because of their effect on the rate of reproduction, primary productivity and temperature are probably the most important controlling factors. However, the correlations between population and density and primary productivity could be improved if the contribution of periphyton was considered. According to Fryer (1968), periphyton is an important food source for several species of Chydoridae.

This and earlier studies have shown that changes in habitat diversity affect population density, as well as diversity of littoral zooplankton. Although lake level fluctuations were monitored, this did not give an adequate reflection of changes in the littoral zone. To determine the effects of eutrophication on littoral zooplankton, quantitative measurements of changes in macrophytes and *aufwuchs* are needed, since these would be more indicative of changes in habitat diversity.

Predation by E. fusiforme and H. formosa does not appear to control population densities of littoral zooplankters in these lakes. However, a measure of total predation might show this to be an important factor, especially when game fish fry are present in the littoral zone.

SECTION VII

TROPHIC STATE STUDIES OF LAKES IN NORTH CENTRAL FLORIDA

A survey of the physical, chemical and biological features of lakes in north central Florida was initiated in 1968. This was undertaken for several specific objectives: (1) to assess the present trophic quality of lakes in this region; (2) to provide baseline data for future studies on rates of changes in the quality of these lakes; (3) to gather sufficient information to evaluate the appropriateness of present trophic state criteria in sub-tropical lakes; and (4) to provide necessary data to construct an equation or index (or indices) for trophic states in sub-tropical lakes.

Sampling programs have been initiated on lakes in three regions of north central Florida: (1) Alachua County (the location of Gainesville); (2) the Central Highlands in Putnam and Clay Counties; and (3) the lower Oklawaha River basin in Lake, Seminole, and Marion Counties. The most extensive sampling program is being conducted on the lakes in Alachua County (for reasons of convenience and also because of the wide range of lake types available within the county). Because of the larger number of lakes in the Central Highlands region, only selected lakes are included in this survey. The two model lakes described in earlier sections of the report are located within this region. The lakes in this area are somewhat different from and generally higher in quality than lakes in Alachua County. These lakes are becoming increasingly important recreationally as locations of homes for vacationers and retirees. Consequently it was considered important to study the trophic nature of these lakes. The lower Oklawaha River basin contains some of the largest and most enriched lakes in Florida. These lakes are important for recreation, and in the past were considered among the best bass fishing lakes in the state. Considerable evidence of rapid eutrophication has been found in some of the lakes within recent years, and agricultural runoff has been implicated as a major contributor of nutrients. In view of these facts it was felt that any study of eutrophication would be incomplete without some information on these lakes. Numerous studies have already been made on the Oklawaha lakes, and studies by groups such as the Florida Game and Fresh Water Fish Commission are continuing. It is not intended that the present study duplicate these efforts but complement them. Because biological information needed in trophic state indices is not available for the lakes, limited sampling on six of the largest lakes in this region has been undertaken.

Both qualitative and quantitative studies of the trophic state of lakes in north central Florida were performed. The results of the qualitative study, using present trophic state criteria, illustrated the need for a new, more quantitative approach to trophic state classifications. In this section both the qualitative and the quantitative trophic state studies are discussed. The quantitative study resulted in the formulation of the Trophic State Index, a novel classification criteria utilizing multivariate techniques.

Qualitative Trophic State Study

This section describes initial attempts to classify the lakes using present trophic state criteria. It is divided into two parts. Part one describes the trophic state of the Alachua County lakes while the second describes the trophic state of the lakes in the Oklawaha River Basin.

Alachua County lakes. All the significant lakes in the county are included in the survey; criteria for significance include size (all lakes larger than about 3 hectares were sampled) and economic or recreational value (any lake with a public or private access road or a permanent dwelling on its shore was considered significant in this regard). Thirty-three lakes in or partly in Alachua County were found to meet these criteria. The locations were determined from U.S.G.S. topographic and county road maps. The lakes and their locations are listed in Table VII-1 and shown in Figure VII-1. Not all the lakes are named, and some of the names are known only to local residents. In some cases conflicting names appear on different maps; we have assumed the most recent map to be correct in these instances. Several other lakes apparently meeting the criteria are indicated on topographic maps but were either swamps or completely dried land at the time of sampling.

Previous limnological efforts in Alachua County have been rather sparse. Because of its unusual characteristics, Lake Mize has been the subject of several studies, including Harkness and Pierce (1940) and Nordlie (1967). Odum (1953) reported some values for dissolved phosphorus in Lake Mize and several other lakes in the county. Nordlie (1967) studied primary production and its limiting factors in Bivens Arm, Lake Mize and Newnan's Lake. The nitrogen cycle, nitrogen fixation and organic color in Lake Mize have been studied by Brezonik (1969). Miscellaneous data on several of the larger lakes can be found in Florida Geological Survey publications (e.g. Clark et al, 1962, 1964).

It is apparent from Figure VII-1 that the lakes are not uniformly distributed throughout the county. Most of the lakes are located in the eastern half of the county, and the four major lakes are in the eastern third. The terrain surrounding the lakes is remarkably varied, considering the small geographical area. Most of the lakes in the eastern part of the county have heavily forested shorelines, but the type of forest varies for different lakes. The large lakes have an outlet and one or more inlet streams, but many of the small lakes have neither.

Table VII-I

LAKES IN ALACHUA COUNTY

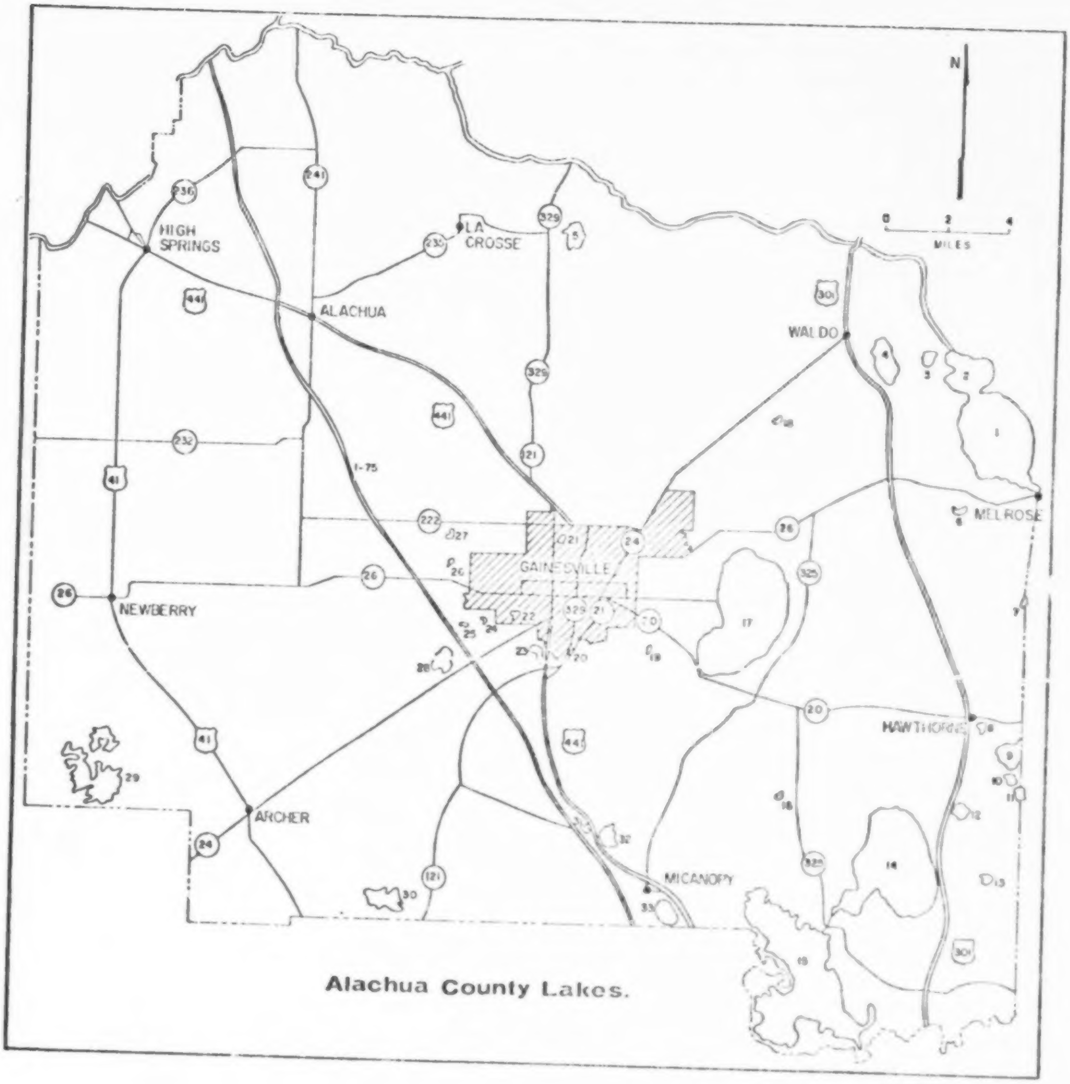
Number	Name	Location	Depth[1]	Area[2]	Type[3]
Santa Fe Basin					
1	Santa Fe	North of Melrose	8.5	1760	OC
2	Little Santa Fe	North of lake (1)	6.5	464	OC
3	Hickory Pond	West of lake (2)	4	32	OC
4	Altho	East of Waldo	4.5	228	OC
5	Cooter Pond	North central part of county	3	124	M
Orange Creek Basin					
6	Elizabeth	Southwest of Melrose	2.5	57	MC
7	Clearwater	Southeast of Melrose	3		O
8	Hawthorn	Hawthorn	3.5	35	EC
9	Little Orange	Southeast of Hawthorn	3	241	MC
10	Unnamed	South of lake (9)	4	50	MC
11	Moss Lee	Southeast of lake (10)		57	
12	Jeggord	South of Hawthorn	4	85	D-MC
13	Still Pond	East of Lochloosa			
14	Lochloosa	Southeast part of county	3	2484	E
15	Orange	Southeast part of county	3	3105	E
16	Palatka	South of lake (17)	1	25	D-S
17	Newnan's	East of Gainesville	2	2562	HEC
18	Mize	Northeast of Gainesville	22	0.9	D-OC
19	Trout	Southeast of Gainesville	1.5	15	D-EC
No Surface Drainage Region					
20	Meta	Northwest Gainesville	1.5	3.9	M
21	Unnamed	South Gainesville	3	1.8	E
22	Bivens Arm	South Gainesville	2	70	HE
23	Alice	U. of F. campus	2	37	S
24	Clear	Southwest Gainesville	2	4.3	EC
25	Unnamed	West of Gainesville	2	7.4	M
26	Unnamed	South of lake (27)	—	2.2	D-MC
27	Unnamed	Northwest of Gainesville	5	5.4	M
28	Kanapaha	Southwest of Gainesville	1	84	E-S
29	Watermelon Pond	Southwest part of county	2	632	D-OC
30	Long Pond	West of Micanopy	1.5		D-OC
31	Burnt Pond	West of lake (32)	2.5	23	EC
32	Wauberg	Northwest of Micanopy	5	103	E
33	Tuscawilla	South of Micanopy	2	64	MC

[1] Depth in meters

[2] Area in hectares

[3] Symbols are as follows:

O = oligotrophic
M = mesotrophic
E = eutrophic
HE = hypereutrophic
D = dystrophic
S = senescent
C = high organic color in lake water


N
0 2 4
MILES
HIGH SPRINGS
LA CROSSE
ALACHUA
WALDO
MELROSE
GAINESVILLE
NEWBERRY
HAWTHORNE
ARCHER
MICANOPY
I-75
236
241
235
329
441
232
41
121
222
26
24
325
20
301
1
2
3
4
5
6
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Alachua County Lakes.

Figure VII-1. Alachua County Lakes

On the basis of surface runoff, the county can be divided into three zones as shown in Figure VII-2. The southeastern third of the county lies within the Orange Creek Basin; fourteen county lakes are in the basin, but not all are connected by surface streams. The Santa Fe River basin in northern Alachua County has only five lakes but considerable swampland. The southwestern part of the county, comprising some 300 square miles, is an area from which there is no surface outflow. The few small streams terminate in limestone sinkholes. Fourteen lakes are located in this region, but most of them are small ponds in the vicinity of Gainesville.

Figure VII-2 also indicates surface distribution of geological formations in Alachua County. A brief description of these surface formations (summarized from Clark et al, 1962) is presented below. The Hawthorne Formation is a marine deposit of Miocene Age consisting of thick and sandy clays interbedded with phosphatic limestone. This formation is exposed in central, northern and eastern Alachua County. Higher terrace deposits outcrop in a 70 square mile area in northern Gainesville and north central Alachua County. These deposits are of Pleistocene Age and consist of fine to medium sands, clayey sands, and multi-colored clays. The Citronelle and Alachua Formations are of Pliocene Age. A small area of Citronelle outcrops in eastern Alachua County. This is a nonfossiliferous deltaic deposit of sand, gravel and clayey sand. The Alachua Formation is exposed to western Alachua County and consists of terrestrial deposits of white, gray and colored sands, clayey sands and some multi-colored clays. Vertebrate fossils, limestone and phosphate pebbles and boulders are scattered throughout the deposit. The Ocala Group of Eocene Age limestones is at the surface in western and southern Alachua County. In much of the area shown in Figure VII-2 as having the Ocala Group at the surface, a thin layer of residual sands and clays covers the limestone. The Ocala Group consists of coquina, hard and soft limestones, and dolomitic limestones. The Ocala Group underlies all of Alachua County and is the main part of the Floridan aquifer. Because of the underlying Ocala limestones, Alachua County can be described as generally having a karst topography. Filled and open sinks, sinkhole lakes, solution pipes and lakes and prairies are typical of such areas, and the county has these features in abundance. Further details about the drainage basins and general landforms in Alachua County can be found in Clark et al, (1964).

Large areas of the county are covered with slash pine for pulp purposes, and extensive swamplands exist. Particularly in the northern and eastern areas, the swamplands are forested with cypress and other trees. Consequently much of the surface water in the county is highly colored with organic exudates and plant degradation products. While agriculture in the broad sense occupies an important place in the economy of the county, relatively little land is devoted to annually harvested crops. Corn and watermelons are perhaps the largest crops and are grown in widely scattered areas. Some tobacco is grown in the northwest part of the county, and a few orange groves are located in the south-central

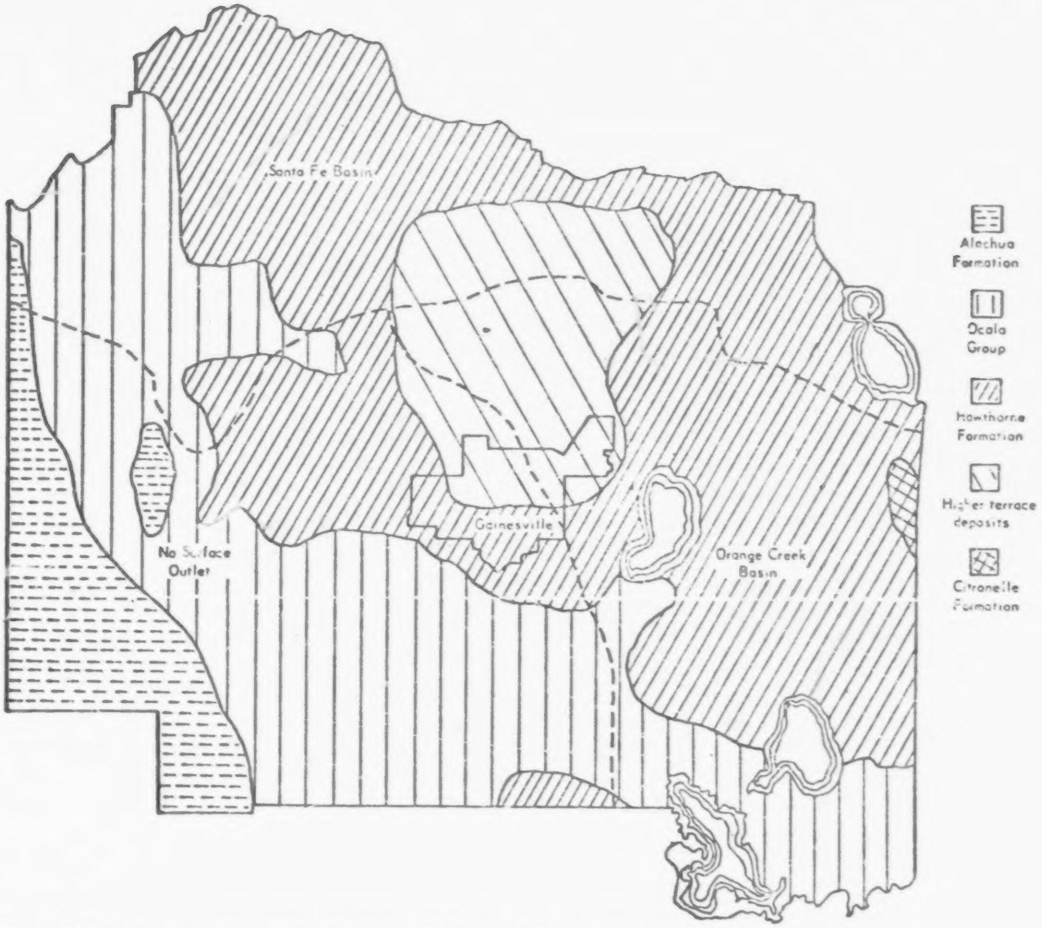
Santa Fe Basin
No Surface Outlet
Gainesville
Orange Creek Basin
Alachua Formation
Ocala Group
Hawthorne Formation
Higher terrace deposits
Citronelle Formation

Figure VII-2. Drainage Basins and Geologic Map of Alachua County (After Clark *et al.*, 1962)

part near Orange Lake. Considerable land is devoted to cattle grazing. In general, agriculture would seem to have little effect on the quality of surface waters in the county. The effects of geology and surface land use on the water quality of individual Alachua County lakes will be discussed in later paragraphs. The physical, chemical, and biological parameters measured in each lake are enumerated in Table VII-2.

The lakes covered in this study range in size from 0.9 hectares (Lake Mize) to 3100 hectares (Orange Lake). Only eleven of the lakes are larger than 100 hectares, and only four of these are larger than 1,000 hectares. Most of the lakes are quite shallow, Lake Mize being the only significant exception. This small lake is a limestone solution sink and has a depth of at least 25 meters. Santa Fe Lake with a maximum depth around 8 meters is the second deepest lake in the county. A majority of lakes have maximum depths of 3-4 meters, but about a third, including some of the larger lakes have maximum depths of 2 meters or less. Bathymetric maps are available for only three (3) county lakes: Newnan's, Mize, and Orange. The depths recorded in Table VII-1 are the maximum values found at several widely scattered sampling stations on each lake. More detailed soundings may locate deeper areas in some lakes, but we believe the values in Table VII-1 to be closely representative of the maximum depths.

Because of their shallow depths, few of the lakes in Alachua County show significant thermal stratification. Lake Mize is the only known monomictic lake, having a well developed thermocline from March to November (Brezonik, 1969). Santa Fe Lake may stratify at least for brief periods in spring but data are not yet available to prove this. Even shallow lakes will stratify briefly during calm periods of intense warming. Such conditions occur most commonly in spring, but can occur in fall and winter also. Evidence for temporary stratification has been found in a number of lakes, but temperatures differ from top to bottom usually by only a few degrees Celsius, which is insufficient to prevent mixing by normal winds.

Conditions in three of the four large lakes (greater than 1,000 hectares) in Alachua County leave much to be desired. Relevant data concerning trophic conditions in these lakes are summarized in Table VII-3. Whether conditions have been affected by cultural influences is not yet certain, but natural factors, especially geological and morphological, seem adequate to explain most of the conditions. Santa Fe Lake is the only oligotrophic lake in this size category. Its maximum depth (8 meters) is not particularly impressive, but it is by far the deepest of the larger lakes. An important factor relating to the lake's oligotrophy is its small drainage basin, the majority of which is forest. A moderate number of cottages and homes dot the shoreline, but no other urban or agricultural eutrophying influences are evident. Santa Fe Lake lies wholly within the Hawthorne Formation, which contains phosphatic clay deposits, but this circumstance is apparently mitigated by the small drainage basin. Phosphate and inorganic nitrogen levels in Santa Fe Lake are relatively high compared to the critical levels suggested to

TABLE VII-2
PARAMETERS MEASURED IN LAKE STUDY

Physical

Lake depth
Lake area
Temperature
Secchi disc transparency
Land use in lake basin
Shoreline development

Chemical

A. Water

Acidity
Alkalinity
Calcium
C.O.D.
Chloride
Color
Conductance
Fluoride
Iron
Magnesium
Manganese
Organic nitrogen
Ammonia
Nitrite
Nitrate
Oxygen, dissolved
pH
Orthophosphate
Total phosphate
Potassium
Silica
Sodium
Suspended solids
Total solids
Sulfate
Turbidity

B. Sediments

Ammonia
Organic nitrogen
Total phosphate
Percent volatile solids
Iron
Manganese
Sediment type (visual classification as peat, muck, etc.)

Biological

Algal identification and counts
Chlorophylls *a*, *b*, and *c*
Total carotenoids
Primary production
Species diversities indices of algae
Visual classification of vegetation surrounding lake

TABLE VII-3

TROPHIC CHARACTERISTICS OF LARGE LAKES IN ALACHUA COUNTY[1,2]

Parameter[3]	Santa Fe L.	Newnan's L.	Orange L.	Lochloosa L.
Secchi disc	2.4	0.6	0.6	0.8
Turbidity	5.4	5.8	6.0	7.9
Sp. conductance	48	60	67	90
Acidity	0.6	0.9	0.5	0.5
Alkalinity	2.6	9.0	15	24
pH	6.5	7.6	7.6	8.3
COD	16	79	56	55
Color	130	490	280	200
TON	0.44	1.13	1.09	1.17
Ammonia-N	0.22	0.02	0.02	0.01
Nitrate-N	0.0	0.0	0.0	0.0
Ortho P	0.001	0.006	0.005	0.004
Total P	0.11	0.05	0.05	0.05
Chloride	10.4	10.8	9.5	10.6
Sodium	7.5	9.8	8.1	9.6
Calcium	1.3	4.0	6.0	10.0
Iron	0.02	0.06	0.02	0.02
Manganese	0.008	0.003	0.050	0.002
Silica	0.11	0.68	0.57	0.16
Organism count	28	2525	2234	5670
Chlorophyll a	5.56	8.62	9.68	12.5
Primary production	13.5	53.6	43.0	35.6

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[1] Lakes larger than 1,000 hectares.

[2] Data from December, 1968, sampling; data from June, 1968 show similar trends. Organisms counts are from June samples since counts from December samples are not yet available. They are presented for comparative purposes among themselves only and should not be compared with the other chemical and biological results (from December). Each number represents a single determination on a composite sample taken from three stations in the lake.

[3] Units for the parameters are in mg/l except as follows: Secchi disc transparency in meters; specific conductance in μmho cm^{-1}; acidity and alkalinity in mg/l as CaCO$_3$; pH in pH units; color in mg/l as P +; organism counts in numbers/ml; chlorophyll a in mg/m^3; and primary production in mg C/m^{3-} hr on composite samples run in a laboratory incubator.

stimulate blooms in north temperate lakes, but concentrations are lower than in the other large lakes. The biological data are all indicative of oligotrophic conditions; color (which limits light transmissions) and depth are probably contributing factors to this condition.

Newnan's, Orange, and Lochloosa Lakes are in the Orange Creek drainage basin, and all show considerable evidence of eutrophy. Newnan's Lake lies within the Hawthorne Formation outcrop, and its major influent stream, Hatchet Creek, drains a large area of the formation north of the lake. Water flows from the southern end of Newnan's Lake through a creek, to a man-made canal and a meandering river into Orange Lake. The northern half of Lake Lochloosa and most of its drainage basin lie within the Hawthorne Formation. Orange and Lochloosa Lakes are connected by Cross Creek, but the major flow from both lakes is through outlets to Orange Creek to the southeast. The high trophic conditions of these lakes are at least partially the result of edaphic considerations. There are no major cultural sources of nutrients for these lakes although fertilized pasture land is drained by Hatchet Creek and the towns of Orange Lake and McIntosh probably release some sewage into Orange Lake.

Newnan's Lake is especially peccant; its extreme shallowness must be a contributing factor. The maximum depth shown on the bathymetric map is 3.6 meters (12 feet), but the mean depth is under 2 meters. With the large surface area, winds must be quite effective in mixing sediments with the overlying water. Orange and Lochloosa Lakes are only slightly deeper, and the geological and hydrological situation implies they are following shortly behind Newnan's Lake on the same avenue of degradation and extinction. All three lakes had profuse algal blooms in June of 1968. The November standing crops were much lower though still blooming according to Lackey's (1945) definition (500 organisms/ml). Essentially all the criteria (see Table VII-3) reaffirm the advanced eutrophy of the three lakes. The large lakes in the Orange Creek basin produce an abundance of fish and are popular with sport fishermen. The advanced eutrophy suggests game fishing may be in a somewhat precarious position, and takeover by rough and trash fish could conceivably be imminent, particularly in Newnan's Lake. Any plans to increase the man-made sources of nutrients to these lakes should be viewed askance.

Results from the medium sized lakes are summarized in Table VII-4. These lakes are widely scattered geographically and present an interesting spectrum of trophic conditions. With the exception of Lake Wauberg, the lakes are in good condition. Wauberg is in an advanced state of eutrophy with frequent and obnoxious algal blooms. The reasons for this condition are not entirely clear. The lake is not excessively shallow (maximum depth is at least 5 meters) and receives no urban runoff, sewage effluent or large amount of agricultural runoff. The drainage basin seems small and is in the Ocala Limestone Formation. In past years the lake was used extensively for picnicking and swimming; a semi-private beach and restaurant were located on the lake. But the potential nutrient additions from these sources seem inadequate to explain the present conditions. The University of Florida now owns the land around the lake and operates it as a camp and recreational facility for the university community.

TABLE VII-4

TROPHIC CHARACTERISTICS OF MEDIUM-SIZE ALACHUA COUNTY LAKES[1,2]

Parameter	Altho	Cooter	Little Santa Fe	Little Orange	Tuscawilla	Watermelon	Wauberg
Secchi disc	1.7	1.2	1.3	1.0	1.2	--[3]	0.9
Turbidity	3.3	4.5	6.3	4.4	3.3	4.0	10.1
Sp. conductance	49	63	50	54	55	32	59
Acidity	1.3	1.4	3.2	4.9	6.0	2.76	0.0
Alkalinity	3.2	4.8	1.6	1.1	12.8	0.0	15.7
pH	6.5	6.9	5.7	5.9	6.6	4.8	8.3
COD	22	87	31	68	52	23	25
Color	250	250	385	495	625	285	125
TON	0.62	1.12	0.57	0.89	0.85	0.86	1.71
Ammonia-N	0.23	0.45	0.26	0.16	0.03	0.20	0.09
Nitrate-N	0.03	0.01	0.02	0.00	0.03	0.03	0.00
Ortho-P	0.002	0.003	0.000	0.005	0.024	0.001	0.005
Total P	0.09	0.16	0.10	0.04	0.28	0.05	0.15
Chloride	10.1	7.6	9.7	8.8	7.7	6.2	8.7
Sodium	7.2	5.7	7.0	6.6	6.0	4.5	9.4
Calcium	2.0	2.2	1.3	2.2	4.0	0.5	6.0
Iron	0.01	0.01	0.03	0.04	0.03	0.01	0.00
Manganese	0.008	0.009	0.014	0.019	0.003	0.042	0.004
Silica	0.30	0.81	0.31	0.31	2.26	0.08	0.17
Organism count	633	431	150	2352	341	125	9288
Chlorophyll a	4.84	21.9	3.28	4.11	5.76	6.44	30.1
Primary production	10.3	87.0	6.6	12.7	12.2	5.33	124.3

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[1] Lakes between 100 and 1,000 hectares

[2] See Table VII-3 for sampling dates and units of parameters

[3] Disc visible to bottom (1.6m)

Lake Altho and Little Santa Fe Lake are classified as colored oligotrophic. The two lakes are connected by an improved canal, and together with Santa Fe Lake, they form the headwater of the Santa Fe River. Santa Fe and Little Santa Fe Lakes in a sense are one lake with two basins separated by peninsulas which constrict the water to a short channel several hundred yards wide. Both Altho and Little Santa Fe are moderately deep (for this area) with maximum depths of 5 and 6.5 meters, respectively. Both have relatively small drainage basins and no sources of cultural enrichment other than a relatively small number of summer cottages and homes. Little Orange Lake, in the Orange Creek basin, is somewhat similar to the above two lakes, although it is more highly colored (about 500 ppm in November) and shallower (maximum depth 3.5 meters). The lake is surrounded by forest and is dotted with cottages, but there are apparently no major cultural influences. The lake is somewhat difficult to classify. Its high color implies dystrophy, but the lake has moderate nutrient levels and a varied population of diatoms, blue-green algae and green algae. The lake has been tentatively classified mesotrophic-colored.

Watermelon Pond is an irregularly shaped lake in the southwest area of the county. The lake has a moderate color, and except for its shallowness and low pH, the data conform to the usual criteria for oligotrophy. Cooter Pond is in the Santa Fe drainage basin but is not connected to the river by a permanent surface outlet. The lake is now surrounded by pasture, but until recently groves of tung trees were cultivated on the land. The general conditions now suggest mesotrophic to eutrophic conditions. The shallowness (2.5 meters maximum depth) implies a small capacity to assimilate more nutrients, and the lake appears to be susceptible to further eutrophication by agricultural runoff and cattle wastes. Tuscawilla Lake occupies a gently sloping depression in a rather flat region south of Micanopy. The lake is shallow and in periods of drought (such as spring of 1968) its area shrinks considerably. The lake is highly colored and has a low ionic content. Nitrogen levels are moderate but phosphorus is high, and an abundance of macrophytes is found in the littoral zone. The chemical conditions suggest mesotrophy, but the shallowness and extensive macrophytes imply the lake may be approaching senescence.

Thirteen lakes scattered throughout Alachua County are in the size range 10-100 hectares. Included are lakes in all classifications; conditions relevant to trophic state are summarized in Table VII-5. Space does not permit discussion of all these lakes, but it is pertinent to note that three of the four Gainesville area lakes in this size class show evidence of cultural effects. Bivens Arm receives urban runoff from a small stream in the southern part of Gainesville and has probably been affected by University of Florida experimental cattle farms on its northwest shore. The lake has an interesting history; the U.S.G.S. topographic map of Gainesville dated 1895 shows Bivens Arm connected with Alachua Lake (Payne's Prairie), both of which were then dry. The latter never became a (water-filled) lake again, but Bivens Arm is now a permanent lake separated from Payne's Prairie by built-up roads.

TABLE VII-5
TROPHIC CHARACTERISTICS OF SMALL LAKES IN ALACHUA COUNTY[1,2]

Parameter	Alice	Bivens Arm	Burnt	Eliza-beth	Haw-thorne	Hick-ory	Jeg-gord	Kana-paha	Long	Moss Lee	Palatka	Trout	#10
Secchi disc	--[3]	0.9	0.9	0.9	1.2	2.1	1.2	0.6	--[3]	2.0	--[3]	0.6	1.6
Turbidity	5.3	10.5	4.9	3.9	3.9	2.8	7.5	7.2	3.3	5.4	3.3	1.8	4.4
Sp. cond.	533	263	67	38	185	39	53	166	16	43.0	22	41	44
Acidity	13.4	0.0	3.7	2.1	1.1	0.9	2.7	4.0	6.4	2.8	7.4	8.9	5.0
Alkalinity	178	139	15	2.0	86	1.8	0.6	70.5	0.0	1.2	0.0	1.2	2.5
pH	7.4	8.5	6.8	5.9	8.0	6.6	5.2	7.3	5.1	5.9	4.8	5.3	6.0
COD	12	65	66	48	37	21	26	78	38	46	72	64	48
Color	130	75	620	155	95	160	345	185	240	278	185	990	305
TON	0.33	1.19	1.87	0.72	1.22	0.65	0.41	3.84	0.89	.79	0.86	1.55	0.81
Ammonia-N	0.01	0.01	0.47	0.08	0.05	0.13	0.11	0.96	0.05	.04	0.14	0.40	0.06
Nitrate-N	0.00	0.00	0.00	0.07	0.01	0.00	0.01	0.03	0.02	.10	0.00	0.11	0.01
Ortho-P	0.070	0.020	0.039	0.005	0.003	0.017	0.005	0.014	0.001	.010	0.002	0.14	0.027
Total P	0.59	0.32	0.36	0.11	0.08	0.04	0.12	0.42	0.04	.043	0.08	0.16	0.10
Chloride	16.7	15.3	9.6	7.5	11.2	10.0	8.6	8.0	4.4	8.9	3.8	7.9	8.8
Sodium	16.0	15.0	6.5	5.4	11.0	6.0	7.7	10.9	2.5	4.9	3.1	6.0	6.6
Calcium	71	50	10.0	1.9	33.0	0.9	0.5	19.0	0.6	1.8	0.4	1.6	1.7
Iron	0.01	0.01	0.04	0.5	0.00	0.01	0.03	0.02	0.01	.00	0.01	0.1	0.02
Manganese	0.003	0.003	0.007	0.019	0.003	0.025	0.027	0.01	0.033	.011	0.005	0.05	0.012
Silica	12.7	1.42	0.64	0.68	0.27	0.30	1.56	0.09	0.18	.017	0.71	1.80	0.35
Organism count	16	2600	1372	625	26,209	119	3824	11,736	--	1			
Chlor a	1.60	11.0	21.4	2.98	19.4	6.36	4.28	9.48	2.56	3.14	3.34	10.8	3.29
Prim. prod.	0	77.5	54.4	0.58	55.5	7.52	4.25	26.9	1.42	12.9	3.36	10.5	17.4

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[1] Lakes between 10 and 100 hectares.

[2] See Table VII-3 for details on sampling dates and units of parameters.

[3] Disc visible to bottom.

Sediment cores would provide considerable information on the nature of Bivens Arm when it was connected with Alachua Lake and the ontogeny of the lake since it was separated and refilled. The lake may have been eutrophic all along; but it seems likely that the above nutrient sources have intensified conditions in the recent past.

Lake Alice has been classified senescent. This lake was once eutrophic, but in recent years nearly all of the lake's surface has been covered with water hyacinths. The lake is shallow, and decaying vegetation produces obnoxious odors. Treated sewage from the University of Florida waste treatment plant enters the east side of the lake, but nutrient concentrations in the water do not reflect this source of enrichment. The extensive hyacinth growths are evidently effective nutrient removers. The lake is almost devoid of phytoplankton as a result of the light cover provided by the hyacinths, the relatively low nutrient concentrations and perhaps antibiotic effects of the macrophytes. A large volume of cooling water from the University steam plant enters Lake Alice daily. This undoubtedly has an important effect on the lake's biota, and probably prevents planktonic populations by a flushing effect. In 1970 a restoration program was carried out on Lake Alice which eradicated all of the hyacinths from the lake surface. This program hopefully will improve the lake's quality of surface water.

Lakes Kanapaha and Hawthorne are also culturally enriched. The former lake is connected with Kanapaha Sink, the terminus of Hogtown Creek in Gainesville; the latter lake receives some sewage from the town of Hawthorne. Burnt Pond is apparently naturally eutrophic. Its shallowness indicates the lake may not be far from the senescent state. Most of the other lakes in this size category are in relatively good condition. High organic color and relative isolation from urban and agricultural development characterize these lakes.

Nine of the lakes in this survey are smaller than 10 hectares. There are also innumerable small ponds (one hectare or less) scattered throughout the county (particularly around Gainesville). These are usually quite shallow and can hardly be considered as lakes in the usual sense of the word. The nine lakes chosen in this survey include all the large lakes in this size category (i.e. lakes between 3 and 10 hectares) and a few smaller lakes chosen because of their unusual characteristics or potential significance in a broad recreational sense. The trophic conditions of these lakes are summarized in Table VII-6. Lake Mize is perhaps the most interesting of these small lakes, because of its great depth (about 25 meters). The lake exhibits the usual characteristics of dystrophy--high color and acidity, low pH, few organisms, etc. The lake is remarkably similar morphologically and chemically to Lake Mary, Wisconsin, except for the latter's mesomixes. Lake Mize is located in the University of Florida Austin Cary Memorial Forest, which one might presume would augur the preservation of this unusual lake. Unfortunately an enclosure for maintaining and raising waterfowl was recently allowed to be built on the shore, and now over fifty ducks contribute untreated excrement directly to the water.

TABLE VII-6
TROPHIC CHARACTERISTICS OF PONDS AND LAKELETS IN ALACHUA COUNTY[1,2]

Parameter	Clear	Clearwater	Meta	Mize	Still #21	#25	#26	#27	Still Pond
Secchi disc	0.8	1.8	1.4	1.0	0.8	--[3]	--	1.8	.7
Turbidity	10.0	2.8	6.5	3.9	10.6	0.9	0.9	3.9	3.8
Sp. cond.	106	33	86	45	275	106	38	43.0	40
Acidity	0.0	1.5	1.4	5.8	0.3	0.0	9.8	9.0	1.3
Alkalinity	27.6	0.8	27.4	1.4	128	50.4	0.6	5.7	.6
pH	8.9	5.4	7.6	5.6	8.2	8.3	5.3	6.0	6.0
COD	44	14	40	34	50	17	29	28	20
Color	345	25	90	260	165	75	500	220	70
TON	1.38	0.59	0.83	0.51	1.33	0.73	0.74	0.56	.58
Ammonia-N	0.02	0.10	0.09	0.26	0.02	0.07	0.03	0.04	.07
Nitrate-N	0.00	0.00	0.00	0.01	0.00	0.03	0.01	0.00	.02
Ortho-P	0.007	0.003	0.001	0.005	0.004	0.001	0.004	0.012	.006
Total P	0.17	0.05	0.06	0.09	0.25	0.06	0.12	0.20	.016
Chloride	8.2	7.4	8.2	9.2	17.7	3.4	9.1	7.7	7.8
Sodium	7.0	5.2	7.0	5.3	15.0	3.1	6.3	5.6	5.5
Calcium	10.0	0.7	10.0	0.8	48	20.0	0.9	2.1	1.0
Iron	0.04	0.01	0.00	0.05	0.00	0.00	0.05	0.02	.00
Manganese	0.005	0.023	0.003	0.010	0.003	0.016	0.015	0.014	.004
Silica	1.68	0.14	0.14	0.98	2.91	0.57	1.60	0.66	.002
Organism Count	5,896	9	15,160	88	10,840	163	303	18	--
Chlor a	11.4	3.32	5.51	24.2	39.0	0.18	6.86	12.7	1.81
Prim. prod.	69.1	0.33	3.59	7.46	235	6.06	2.09	41.0	0.2

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[1] Lakes smaller than 10 hectares.

[2] See Table VII-3 for details of sampling dates and units of parameters.

[3] Disc visible to bottom.

Lake #27 (unnamed) is unusual in that it is completely covered with duckweed (Lemna) normally indicative of high nutrient conditions. The lake is isolated from urban and agricultural effects and otherwise exhibits oligotrophic characteristics. The lake is moderately deep (for this area)--maximum depth is at least 5 meters. There does not seem to be a satisfactory explanation for the extensive duckweed growth in this lake and its virtual absence in all the other lakes of this survey. Clear lake was evidently named before the onset of a eutrophic condition which contradicts its name. The lake is surrounded by homes with septic tanks and has become eutrophic only in recent years (Furman, personal communication). An extremely dense Anabaena bloom was present in the June, 1968, sample and the lake oscillates between relatively clear and bloom conditions. Lake Meta (in northwest Gainesville) also shows some signs of cultural enrichment from surrounding homes, but to a lesser extent.

Even cursory inspection of the chemical and biological results obtained reveals graphic disparities in trophic conditions among the lakes. In fact inspection of the lakes themselves illustrates this in a dramatic albeit crude way. An attempt to classify the lakes according to the usual trophic types is included in Table VII-1. Some geographical patterns in trophic type are evident but not altogether conclusive. Lakes in the Santa Fe River basin are oligotrophic and somewhat colored. Many of the small lakes in the Orange Creek basin are also oligotrophic and most are highly colored, but the large lakes are eutrophic. Lakes in the southwestern part of the county are quite varied with respect to trophic levels. Some of the small lakes in urban and suburban Gainesville show evidence of eutrophy; cultural influences may have exerted some stress on these lakes.

The trophic criteria do not give clear indications of trophic state in all cases. Some of the smaller lakes have both oligotrophic and eutrophic characteristics, and many lakes have dystrophic characteristics along with oligotrophic or eutrophic conditions. The lakes with oligotrophic and eutrophic criteria are classified as mesotrophic; Lake Elizabeth and Cooter Pond are examples. These lakes may be in a transitional state between the two trophic levels. Alternatively, these may be examples of the inadequacy of trophic criteria developed for temperate lakes when applied to subtropical lakes. The inadequacy of the dystrophic classification is amplified by the results from this study. Over half of the lakes show some signs of dystrophy, i.e. high color, low pH, low ionic solids. However, high color is not always correlated with other criteria for dystrophy. Some colored lakes have neutral or alkaline pH (e.g. Lake Kanapaha) or high calcium and alkalinity (Lake #21). The range of nutrient concentrations and plankton in these lakes is from unproductive to hypereutrophic. It is obvious that one class (dystrophy) is insufficient to describe all these lakes, even though each has several criteria indicating dystrophy. Hansen's (1962) dichotomic classifications where lakes are classified as colored or clear and each of these has the full range of trophic states (oligotrophy to eutrophy) are an improvement over classical typology. However, eutrophication in colored and clear lakes may proceed along different courses, and trophic states in the two classes may not be strictly parallel (e.g. different biota and trophic structures may result from eutrophication in the two classes). Lakes showing partial dystrophy in this study have been classified colored-oligotrophic, colored mesotrophic, etc., as appropriate. A few lakes with rather extreme dystrophic conditions (e.g. Lakes Mize, Palatka, Jeggord, Long Pond) have been tentatively classified as dystrophic along with an alternate classification such as colored-oligotrophic. These are subject to change as the classification scheme becomes further developed and refined.

The shallow lakes present especially difficult problems in classification. Lakes with depths of two meters or less are susceptible to take-over by macrophytes like hyacinths. Thus they could quickly become swamps or bogs and must be near the senescent stage. The present trophic state of these lakes range from dystrophy (Palatka), mesotrophy (Tuscawilla), hypereutrophy (Bivens Arm) to senescence (Alice). It is not clear whether a lake like Tuscawilla has already been through a eutrophic stage and is now in a decreased state of production heading toward senescence or it never reached eutrophic conditions and will pass into senescence without doing so. If lake classifications are to imply anything regarding a lake's ontogeny, and its probable future development, it is important that such questions be resolved. A corollary to the problem of shallow lakes is the problem of lakes with extensive shallow areas but some deeper holes. For example, Newnan's Lake has large areas with a depth of 1 meter or less but has several small regions nearly 4 meters deep (mean depth is about 2 meters). The shallow areas could give rise to extensive growths of rooted or attached macrophytes and develop into swamp or bog, which would indicate senescence, but the deeper areas could remain lacustrine for much longer. In fact, considerable difficulty has been encountered in controlling water hyacinths (not an attached plant) in recent years, which implies the lake, or a large portion of it could become senescent in the near future.

The data in Table VII-3 to VII-6 show a number of interesting correlations. Figure VII-3 indicates a positive correlation between sodium and chloride concentrations in the 33 lakes, implying a common origin for the two ions. However, the estimated line of best fit deviates significantly from the theoretical line for NaCl dissolution with an excess of sodium over chloride. Most of the chloride presumably originates as sodium chloride, probably from atmospheric precipitation (from marine aerosols) and cultural sources. But other salts and weathering of clays must also act as sources of sodium. High sodium and chloride concentrations correspond with lakes having known pollution sources (e.g. Alice, Bivens Arm, and Hawthorne).

Calcium and bicarbonate alkalinity are highly correlated (Figure VII-4). The slope of the line of best fit approaches the theoretical line for dissolution of calcium carbonate:

$$CaCO_3 + CO_2 + H_2O > Ca^{+2} + HCO_3$$

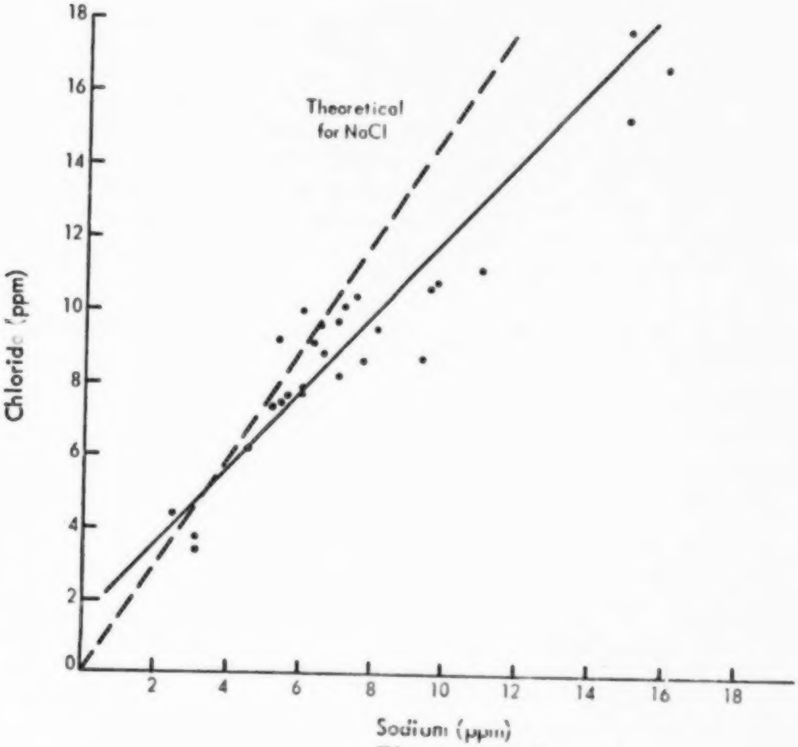


Figure VII-3

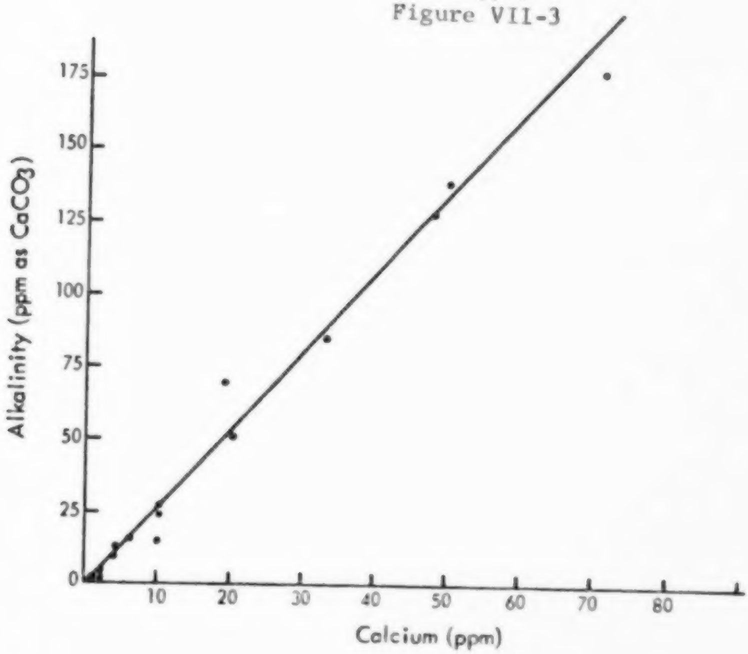


Figure VII-4

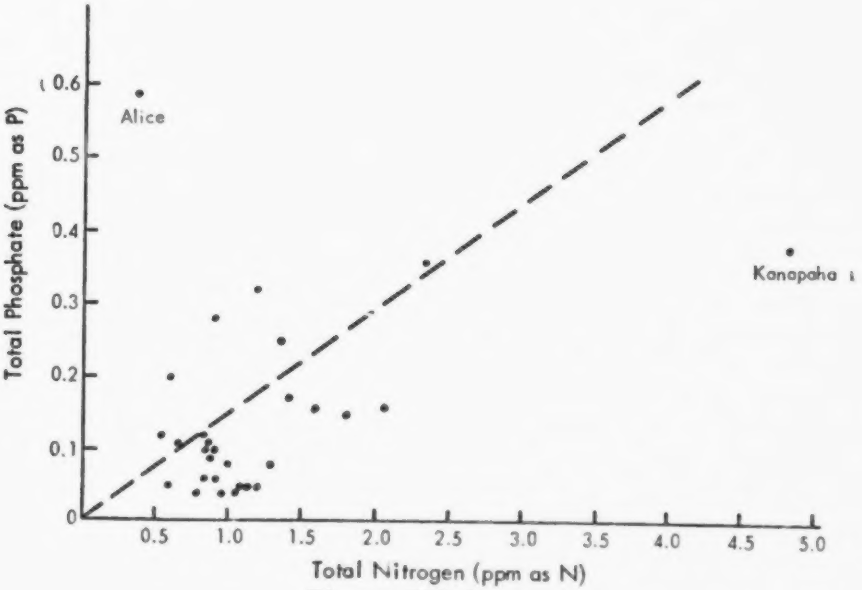


Figure VII-5

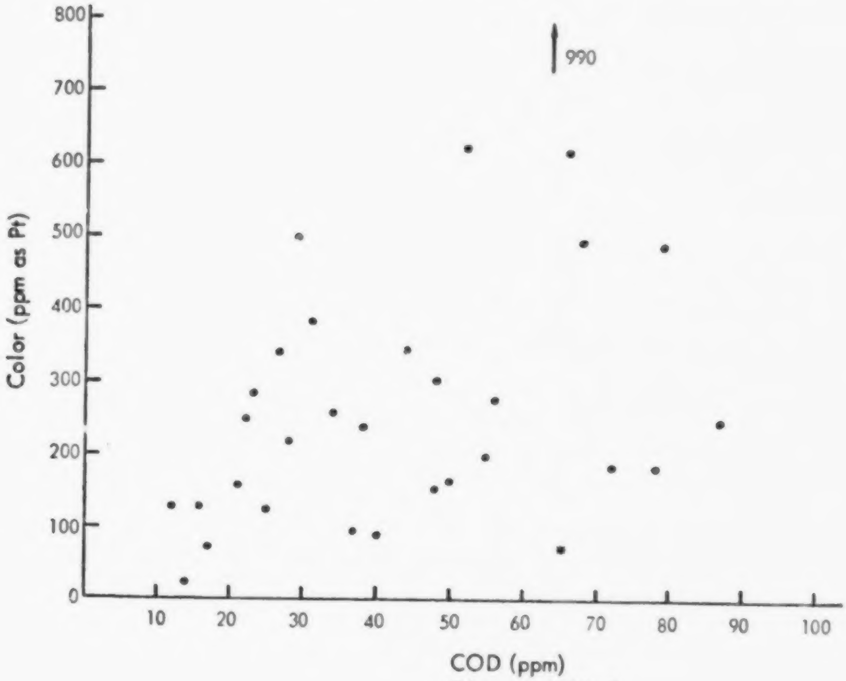


Figure VII-6

implying this to be the source of calcium and alkalinity in the lakes. Most of the lakes have low concentrations of these ions; only nine lakes have calcium concentrations of 10 ppm (as Ca) or greater. The major natural sources of water for the lakes in the county are atmospheric precipitation, and surface and sub-surface runoff through perched water tables in the sandy soil; hence the low calcium concentrations. High calcium suggests a lake receives ground water from the Floridan aquifer (a limestone stratum), which means the lake is either spring-fed or receives waste water from supplies using well water from the aquifer. Most of the lakes with high calcium have known sources of waste water (e.g. Alice, Bivens Arm, Clear, Kanapaha, and Hawthorne). Since high nutrient concentrations are associated with such waters, these lakes are highly enriched. Thus for most of the lakes in Alachua County, calcium ion appears to be a good indicator of cultural eutrophication. The relatively high calcium content of Lochloosa Lake probably results from Magnesia Spring, which drains into Lochloosa Creek about 5 miles north of the creek's confluence with the lake.

There was little apparent correlation between total nitrogen and total phosphate in the December, 1968, sampling of the 33 lakes as indicated by the scatter diagram in Figure VII-5. However, lakes with the most extreme N/P ratios are seriously polluted (e.g. Alice and Kanapaha) and there are some indications that lakes in a particular region have similar N/P ratios. For example, lakes in the Santa Fe River headwaters (Altho, Santa Fe, Little Santa Fe) have similar ratios which are generally higher than the larger lakes in the Orange Creek Basin. The dashed line in Figure VII-5 indicates the usually quoted optimum N/P ratio of 15:1 by atoms for algal growth. Points below the line suggest an excess of nitrogen relative to phosphorus; most of the lakes belong in this category.

Chemical oxygen demand (COD) and color show no correlation for the 33 lakes (Figure VII-6). Evidently there is a considerable variability in non-colored organic matter in the waters. The highest color/COD ratio was 17 (Lake #26). Eight of the lakes have ratios of 10-13 and the remainder of the waters have lower ratios, suggesting large amounts of non-colored organic matter. There is some evidence that low color/COD ratios indicate organic pollution; for example, Bivens Arm had the lowest color/COD ratio (1.15), but other apparently unpolluted lakes (e.g. Palatka) also had low ratios (2.6).

A plot of turbidity versus the inverse of Secchi disc reading (Figure VII-7) also shows considerable scatter, implying other factors control Secchi disc visibility. Inspection of the data suggest color has an important effect; Trout Lake, with a color of 990 ppm, had the highest ratio (0.93) of (Secchi disc)^1/turbidity. A multiple regression of Secchi disc against turbidity and color, after removal of Secchi disc readings affected by shallow bottoms, would probably account for most of the variance.

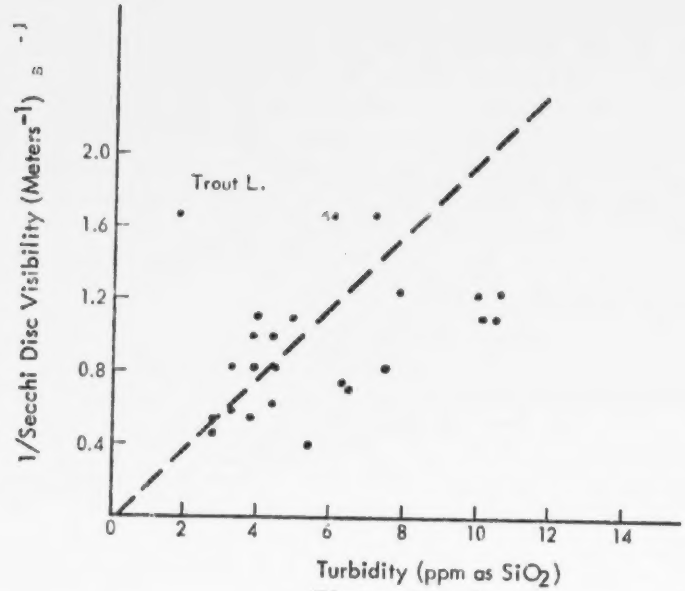


Figure VII-7

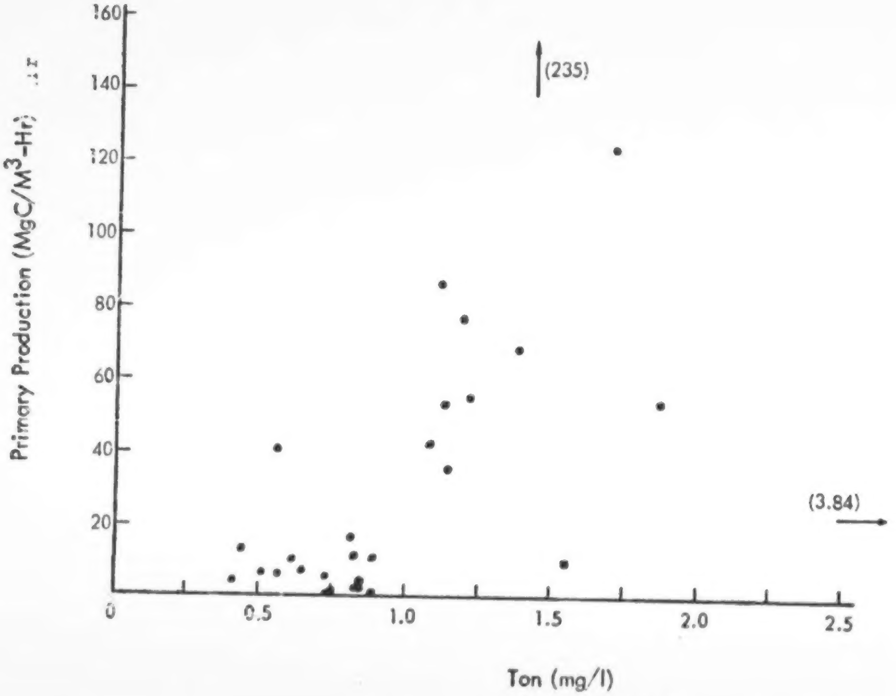


Figure VII-8

A wide range of primary production and chlorophyll a data are encountered in the 33 lakes. Rates of the former ranged from negligible (Lake Alice) to 235 mg C/m^3-hr (Lake #21). In order to facilitate comparison of rates in the lakes, all incubations were carried out under constant light and temperature conditions in a laboratory incubator. In general, highest rates of primary production are associated with lakes showing eutrophic chemical characteristics. However, there does not seem to be any simple quantitative relationship between primary production values and concentrations of nutrients. For example, Figure VII-8 shows the scatter which occurs when primary production is plotted vs total organic nitrogen. Plots of primary production vs inorganic nitrogen and phosphate show similar scatter.

There is also no simple relationship between primary production and depth (Figure VII-9), as Rawson (1955) found for the Great Lakes and some Canadian lakes he studied. There is some uncertainty concerning the meaning of depths used to plot Figure VII-9 (see discussion above). Since bathymetric maps are not available for these lakes, mean depths are unknown; maximum depths for most lakes are probably somewhat greater than the values used here. Some of the variance may be removed with accurate measures of mean depth, but primary production values would still seem to be grouped into classes rather than along any linear or curvilinear relationship. The horizontal dashed line in Figure VII-9 represents an arbitrary division between high and low productivity lakes. Points above this line correspond with lakes classed as mesotrophic or eutrophic. The dashed vertical line represents an arbitrary division between deep and shallow lakes; most of the lakes would be classified as shallow productive or shallow unproductive on this basis.

Chlorophyll a concentrations also show a qualitative correlation with other criteria for trophic state (i.e., high chlorophyll a concentrations are associated with lakes classified as eutrophic or mesotrophic). However, quantitative correlations with nutrient concentrations are not evident. The relationship between chlorophyll a and primary production also shows considerable scatter (Figure VII-10), although there would seem to be a significant correlation between the two parameters.

Lakes in the Oklawaha River Basin. The region northwest of Orlando consists of rolling hills occupied by thousands of acres of citrus trees. The area has an abundance of lakes situated in its valleys, including a chain of large lakes in the southern part of the Oklawaha River Basin. These lakes have been popular for recreation and in the past at least one (Lake Apopka) was famous nationally for bass fishing. The quality of several of the lakes has declined radically in recent years and concern has been expressed regarding the cultural eutrophication of the entire chain. Implicated as an important nutrient

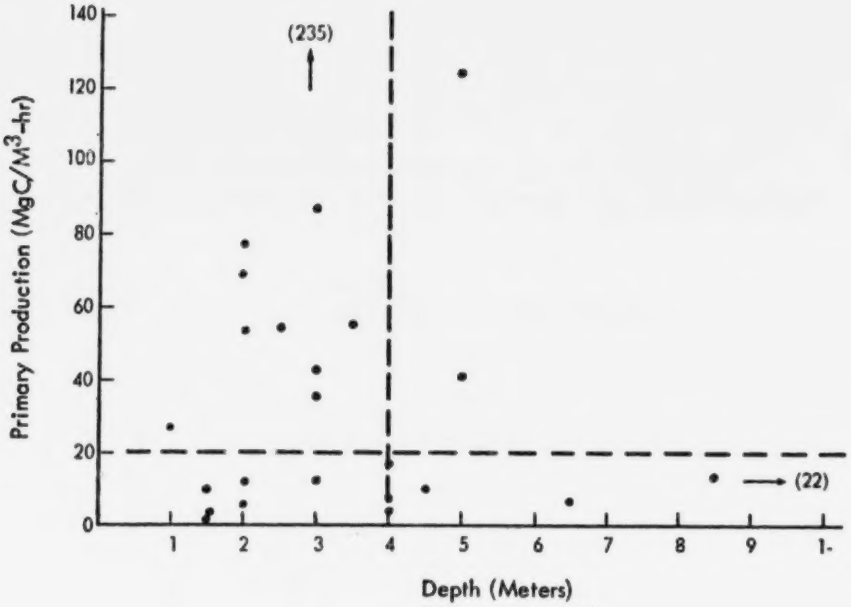


Figure VII-9

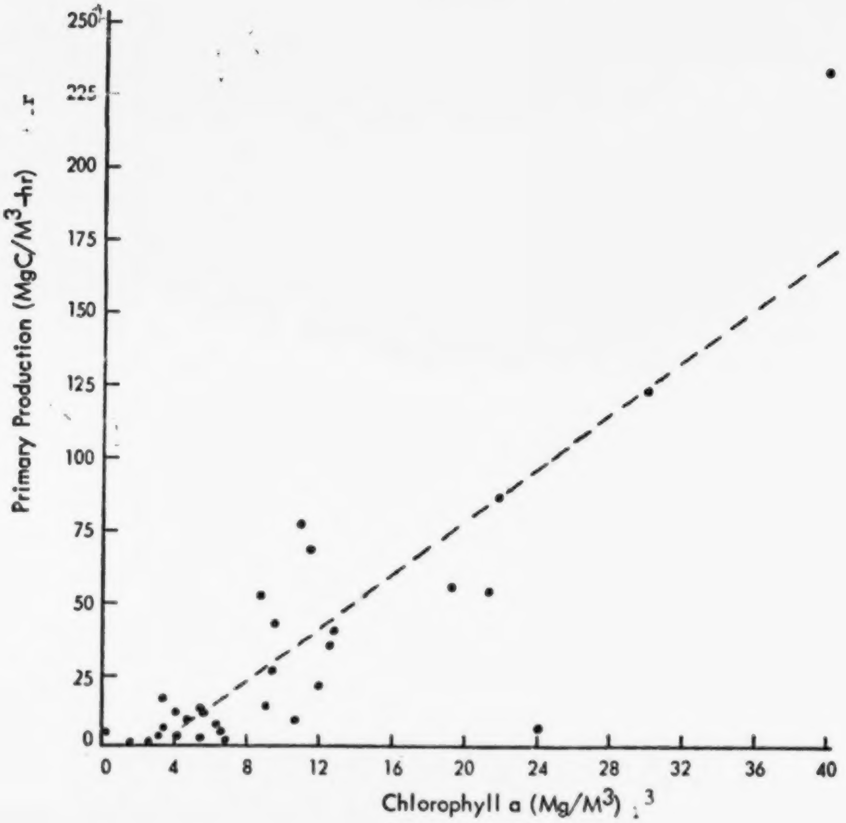


Figure VII-10

source is agricultural runoff-primarily from vegetable farms in reclaimed marsh and wetlands, but also from citrus groves; domestic waste effluent from towns on the lakes' shorelines and waste from citrus concentrate processing plants are also important nutrient sources.

The location of the lakes included in this survey is shown in Figure VII-11 and physical data on the lakes is summarized in Table VII-7.

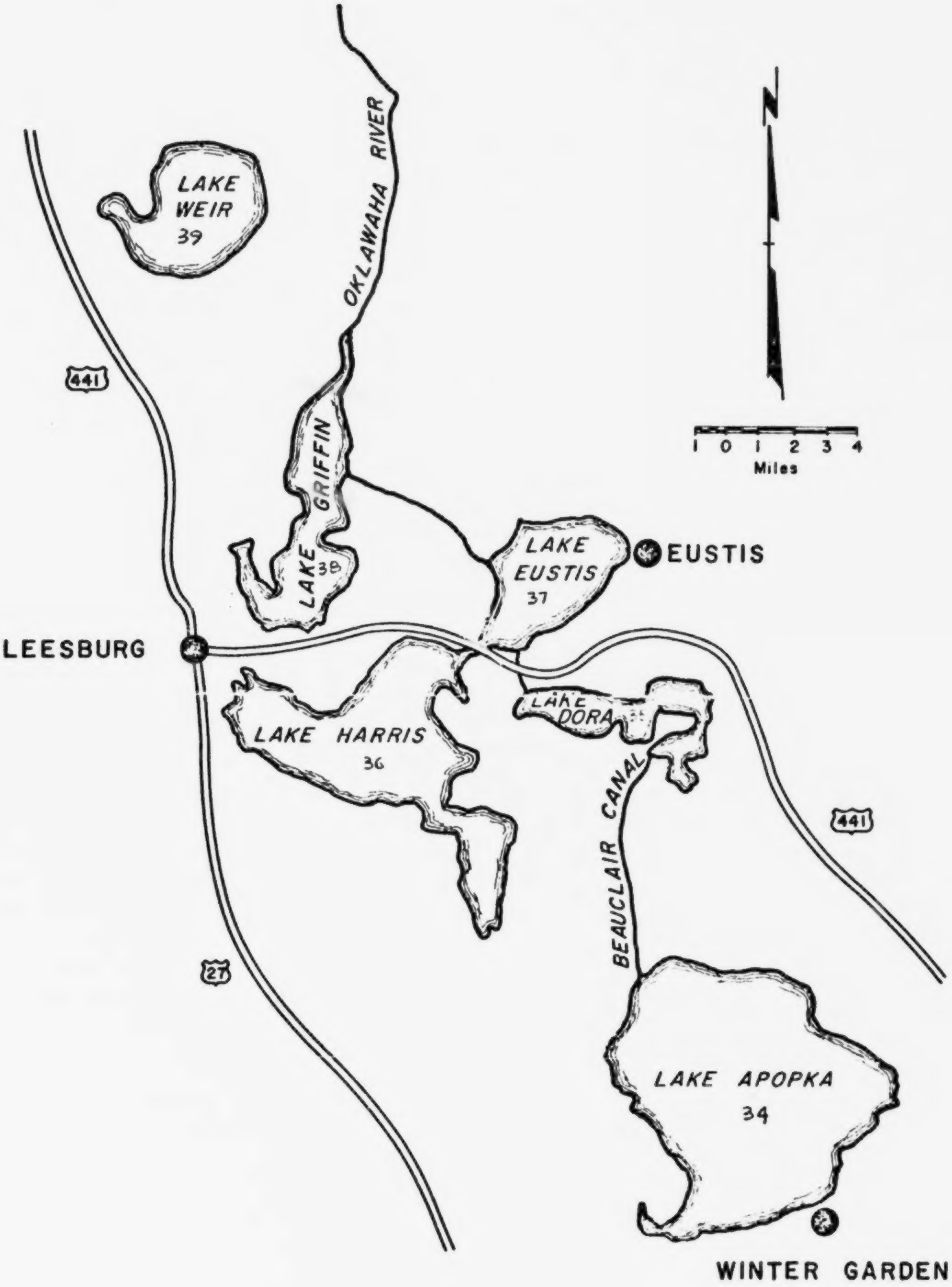
TABLE VII-7
PHYSICAL CHARACTERISTICS OF LAKES IN OKLAWAHA BASIN

Lake	Area (ha)	Depth[1] (m)	Surface Temp. °C	Bottom Temp. °C	Lake Type[2]
Apopka	12,200	2	19.8	19.6	HE
Dora	2,060	3.5	16.7	16.6	HE
Eustis	2,740	5	24.9	24.7	E
Griffin	3,455	3	19.8	18.9	E
Harris	7,090	5.5	22.9	20.0	E
Weir	2,420	7.5	25.7	24.0	M-E

[1] Maximum depth found during sampling. In the case of Lake Apopka, this value also represents the mean depth; maximum depth of this lake is 6 m in a small hole near the southern shore (see Schneider and Little, 1968) for a bathymetric map). A map of Lake Weir is also available (Kenner, 1964) and indicates a maximum depth of 10 m in a small hole near the southern shore.

[2] See Table VII-1 for list of abbreviations.

Lake Apopka is the largest of these lakes, and also the first lake in the Oklawaha chain. This lake is probably the most famous of the chain, but is now considered as the furtherest advanced in the eutrophication process. The lake has been the subject of numerous investigations and reports (see Burgess, 1964; Huffstutler et al, 1965; Schneider and Little, 1968 for details on the recent history of the lakes). Lake Apopka drains into Lake Dora through the Beauclair Canal, and the latter lake drains into Lake Eustis. Lake Harris also drains into Lake Eustis, which drains into the last important lake of the chain, Lake



LAKE WEIR
39
OKLAWAHA RIVER
N
1 0 1 2 3 4
Miles
441
LAKE GRIFFIN
38
LAKE EUSTIS
37
EUSTIS
LEESBURG
LAKE HARRIS
36
LAKE DORA
BEAUCLAIR CANAL
441
27
LAKE APOPKA
34
WINTER GARDEN

Figure VII-11: Location of Lakes in Lower Oklawaha River Basin.

Griffin. While not directly in the chain, Lake Weir, about 10 miles northwest of Lake Griffin, is within the Oklawaha drainage basin. None of these lakes has received the attention accorded to Lake Apopka, but some prior studies are available. The Florida Game and Fresh Water Fish Commission is performing a detailed study on the trophic states of Lakes Apopka, Eustis, and Weir, and their data will be useful in developing and analyzing trophic criteria.

The six lakes were sampled for the chemical and biological parameters shown in Table VII-2. The results are summarized in Table VII-8. The trophic characters of the lakes are revealed quite unambiguously by these initial results. All the lakes in the Oklawaha chain are eutrophic. Lake Weir is in considerably better condition than the lakes in the chain, but it is on the border between mesotrophy and eutrophy. Lakes Apopka and Dora have the most advanced cases of eutrophy; all relevant chemical and biological data indicate a high degree of enrichment and productivity. The shallowness of Lake Apopka implies the lake could pass from hypereutrophy into senescence if macrophytes (e.g. hyacinths) are allowed to take over. Lakes Eustis and Griffin present slightly improved characteristics compared to the first two lakes. The chemical and biological conditions of Lake Harris are the best of the five lakes in the chain. The trophic criteria definitely indicate a eutrophic state, but perhaps not the hypereutrophy of the other lakes. Perhaps some of the water quality improvements in Lakes Eustis and Griffin result from dilution of enriched Lake Dora effluent by relatively nutrient poor Lake Harris water.

The water chemistry of Lake Weir differs considerably from the other lakes. Alkalinity and hardness are low in Lake Weir and pH is near neutrality. Major cations and anions are moderate to low and a specific conductance of 135 μmho cm^{-1} reflects this fact. Lakes in the chain have high alkalinities and hardness and pH values near 9 or above. Major ion concentrations are high and specific conductance ranges from 230-335 μmho cm^{-1}. The correlation between high trophic level and high concentrations of major ions in these lakes and relatively low trophic level and low ionic content in Lake Weir might imply that eutrophication involves an increase in dissolved solids and a change from soft to hard water. In fact dissolved solids has been considered a trophic criterion and was used as such by Beeton (1965) and others. A certain degree of correlation would be expected between increasing nutrients and increasing dissolved solids where enrichment results from domestic waste effluent and the town's water supply is hard ground water. This is the case with Lake Apopka, where the city of Winter Garden obtains its drinking water from wells. The meager background chemical data on the lake indicate some increases in dissolved solids and hardness in the period of record, but the lake water was relatively hard and high in dissolved solids over 40 years ago. Black and Brown (1951) reported a chemical analysis of Lake Apopka from August, 1924, made by the U. S. Geological Survey. Table VII-9 compares their results for major ions with the results from this study. While the lake was probably quite productive in 1924, serious degradation in water quality has occurred

TABLE VII-8

CHEMICAL AND BIOLOGICAL CONDITIONS IN OKLAWAHA LAKES, OCTOBER, 1968[1]

Constituent[2]	Apopka	Dora	Harris	Eustis	Griffin	Weir
Diss. O_2	11.2	11.4	9.7	8.78	8.4	7.60
Cond.	330	335	230	275	290	135
pH	9.5	9.5	8.8	8.9	8.9	7.2
Alkalinity	126	130	91	104	112	15.1
COD	113	157	48	112	78	25.
Color	30	43	13	28	25	5
Secchi Disc	0.3	0.3	0.8	0.6	0.5	1.2
Turbidity	27	28	20	25	28	3
Sus. solids	43	77	13	46	27	22
TON	3.8	5.3	1.7	4.1	3.0	0.97
NH_3-N	0.18	0.17	0.19	0.20	0.18	0.25
Ortho PO_4	0.016	0.108	0.010	0.014	0.014	0.006
NO_2-N	0.004	0.005	0.004	0.006	0.007	0.004
NO_3-N	0.09	0.11	0.05	0.24	0.09	0.05
Total P	0.24	0.39	0.035	0.22	0.20	0.021
SiO_2	6.4	0.05	3.4	1.4	0.40	0.34
Fe (total	T	0.01	0.01	0.01	0.01	T
Mn (total)	T	0.003	0.006	0.005	0.003	0.005
Ca^{+2}	25.1	30.5	23.1	26.3	28.9	1.4
Mg^{+2}	14.7	14.2	6.1	10.7	9.6	3.1
Na^{+}	11.7	18.1	9.7	14.5	14.0	15.5
K.$^{+}$	2.9	3.4	0.9	2.4	2.1	1.0
Cl^{-}	21	22.3	12.8	18.7	17.5	26.8
$SO_4^{=}$	10.2	12.3	4.9	7.1	6.7	4.8
Chor *a*	34.1	72.1	17.7	33.1	45.4	8.4
Prim. prod.	0.386	1.02	0.037	0.274	0.183	0.011

---

[1] Results are average values for composite samples from three stations in each lake.

[2] Chemical species in mg/1 except as follows: alkalinity in mg/1 as $CaCO_3$, nitrogen species in mg N/1, phosphorus species in mg P/1, color in mg/1 as Pt. specific conductance in μmho cm^{-1}, Secchi disc visibility in meters, chlorophyll *a* in mg/m^3.

[3] Primary production in mg C fixed/1-hr. Composite lake water samples were run in a laboratory incubator.

TABLE VII-9
COMPARISON OF MAJOR IONS IN LAKE APOPKA IN 1924 AND 1968[1]

Constituent	1924[2]	1968[3]
Total dissolved solids	129	184
Calcium	18	25.1
Magnesium	8.3	14.7
Sodium and Potassium	11	13.4
Iron	0.17	T (<0.01)
Bicarbonate	89	152
Sulfate	4.5	10.2
Chloride	17	21
Silica	6.7	6.4

---

[1] Results in mg/l; potassium expressed in terms of sodium (Na).

[2] From Black and Brown (1951); original data by the U.S. Geol. Surv. (Water Supply Paper 596-G), Washington, D.C. (Collins and Howard, 1927).

[3] Data from this study.

only in the last 15-20 years. Thus increasing hardness and dissolved solids would not seem to be a necessary feature of cultural eutrophication. Quite possibly eutrophication in Lake Weir may proceed along a different course not involving increases in solids and hardness--as has apparently been the case with lakes in the Orange Creek Basin (e.g. Newnan's Lake).

It is difficult to draw firm conclusions regarding trophic state from one set of samples. Various parameters may respond to seasonal changes differently in each lake. With this limitation in mind, we would tentatively systematize the trophic conditions of these lakes in the following sequence:

Lake Apopka = hypereutrophic--near senescence

Lake Dora = hypereutrophic

Lakes Eustis and Griffin = eutrophic

Lake Harris = moderately eutrophic

Lake Weir = mesotrophic to moderately eutrophic

The above sequence is somewhat relative since it is difficult to compare lakes in different regions in a quantitative manner. Eutrophy in Lake Apopka is considered more advanced than in Lake Dora because of the extreme shallowness of the former lake. The chemical and biological results are similar for the two lakes; in fact Lake Dora had more extreme values for some trophic criteria. But it is somewhat deeper and because of this perhaps more amenable to restoration.

Conclusions. The results obtained in this phase of the eutrophication study substantiate the complexities involved in defining and quantifying lacustrine trophic states. The chemical and biological information obtained on each lake has enabled us to classify the lakes qualitatively as oligotrophic or eutrophic, etc. The correlations among different trophic indicators are generally good for these lakes--on a qualitative basis, but simple regressions of one criterion versus another in all cases showed large amounts of scatter or unexplained variance. Trophic state and the interrelations among trophic criteria are multivariate functions. Quantification of these phenomena requires more sophisticated mathematical analysis than those employed above. Stochastic modeling procedures seem to be particularly appropriate to the problem of quantifying trophic indices with masses of data collected from different lakes. Multivariate techniques, such as canonical correlation, multiple discriminant analysis and factor analysis (principal component analysis), were used to synthesize quantitative measures of trophic state for sub-tropical lakes. This is discussed in the following section.

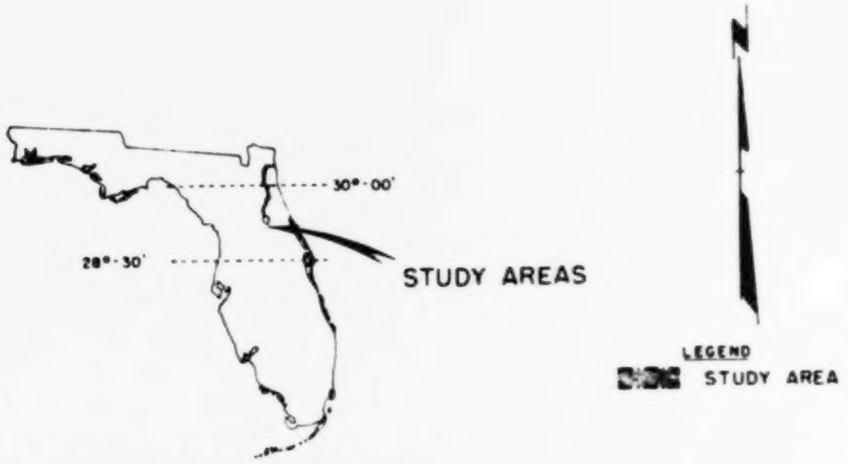
Quantitative Trophic State Study

In establishing the trophic state index the apparent response of lakes to nutrient enrichment has been envisioned as a multi-dimensional hybrid concept described by several physical, chemical and biological trophic state indicators and appropriate multivariate statistical methods have been used to analyze the relationships between nutrient enrichment and trophic state. One aspect of these studies was concerned with formulating a Trophic State Index (TSI) that would provide a means for quantifying trophic state on a numerical scale. Such an index is desirable for the following reasons: (1) a TSI would facilitate identification and comparison of lakes, (2) in the dynamic process of trophic state change, a TSI provides a method for determining the trophic state of a lake at any particular time and evaluation of the index over time should provide information on the direction and rate of lake succession, (3) a TSI should be used in quantifying the response of the lake ecosystem and its environment (watershed conditions influencing nutrient enrichment). Such relationships should in turn be useful in lake-basin management models, where it may be of particular interest to know how much nutrient enrichment will cause significant change in lake water quality.

In formulating the TSI seven trophic state indicators were considered as describing the concept of trophic state; viz. primary production (PP), chlorophyll a (CHA), total phosphorus (TP), total organic nitrogen (TON), conductivity (COND), inverse Secchi disc transparency (1/SD), and the inverse of a cation ration $(\frac{Ca + Mg}{Na + K})$ (1/CR) (after Pearsall, 1922). Inverses of the last two parameters were used so that each indicator exhibited a positive response to eutrophication (i.e. the indicator value increases with increasing eutrophy). Data for these indicators had been obtained from an extensive one year study of the chemical, biological, physical, and morphometric characteristics of fifty-five Florida lakes contained within the areas indicated in Figure VII-12. The means, standard deviations, and the correlation matrix between the seven indicators are summarized in Table VII-10. A principal component analysis was performed on the correlation matrix and the first principal component extracted. The first principal component was modified by adding a constant to prevent negative values and interpreted as the Trophic State Index. The method of principal component analysis is described by Morrison (1967). The formula for evaluating TSI is given by:

$$\begin{aligned} TSI = {} & .919(1/SD) + .800(COND) + .896(TON) + .738(TP) + \\ & .942(PP) + .862(CHA) + .635(1/CR) + 5.190 \qquad (1) \end{aligned}$$

where the terms in parentheses refer to standardized indicator values since the units of the indicators differ. Standardization involves the subtraction of the mean value of the indicator from the raw data value and dividing by the indicator standard deviation. The appropriate means and standard deviations are from Table VII-10. Calculation of the TSI then is a straight forward process of substituting the standardized trophic state indicator values for a lake into equation (1). The TSI's were calculated for fifty-five Florida lakes and ranked in descending order of magnitude in Table VII-11. In addition, the TSI's of Lake Tahoe, Lake Erie, and Lake Superior were calculated and inserted in Table VII-11. Secchi disc values influenced by organic color were color corrected by a multiple regression procedure not described here.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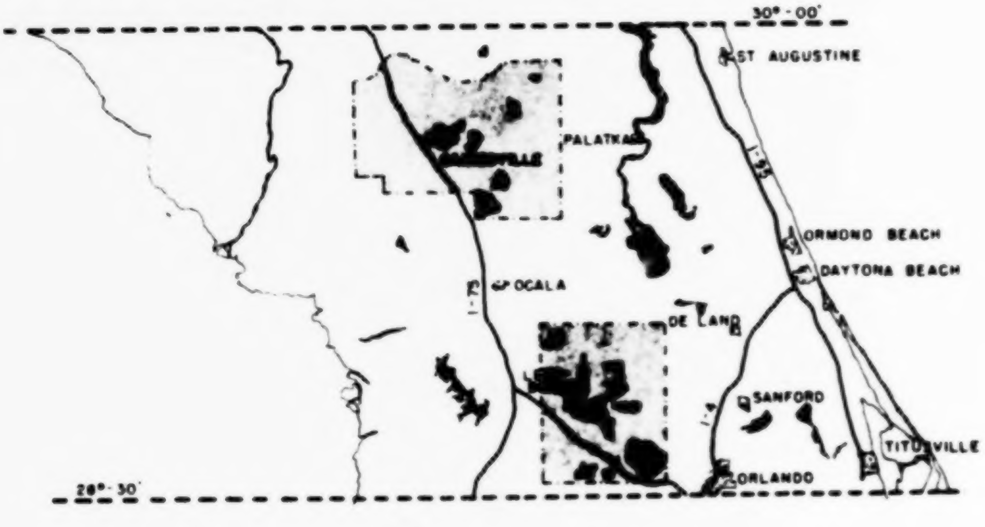
VICINITY MAP SHOWING MAJOR
LAKE STUDY AREAS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TITUSVILLE
ORLANDO
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FIGURE VII-12

LOCATION MAP SHOWING MAJOR LAKE STUDY AREAS

TABLE VII-10

MEANS, STANDARD DEVIATIONS, AND CORRELATION MATRIX FOR SEVEN TROPHIC STATE INDICATORS

Indicator[a]	Mean	Standard Deviation
1/SD	.84	.77
COND	93.1	101.3
TON	1.02	.82
TP4	.125	.177
PP	44.8	82.3
CHA	16.9	19.8
1/CR	1.47	1.63

Correlation Matrix:

	1/SD	COND	TON	TP4	PP	CHA	1/CR
1/SD	1.000	.617	.880	.542	.927	.784	.502
COND		1.000	.582	.762	.654	.540	.560
TON			1.000	.500	.890	.788	.474
TP4				1.000	.576	.553	.440
PP					1.000	.859	.478
CHA						1.000	.402
1/CR							1.000

[a] Key to indicator abbreviations in text

TABLE VII-11

FLORIDA LAKES RANKED WITH RESPECT TO THE TROPHIC STATE INDEX (TSI)

Lake	TSI
(a) HYPEREUTROPHIC GROUP	(≥ 10.0)
Lake Apopka (34)[a]	22.1
Lake Dora (35)	18.5
Unnamed 20 (20)	18.5
Biven's Arm Lake (23)	14.7
Lake Griffin (38)	13.7
Lake Kanapaha (28)	13.5
Lake Alice (22)	10.7
Lake Eustis (37)	10.5
(b) EUTROPHIC GROUP	(7.0-9.9)
Lake Erie*	9.8
Lake Hawthorne (8)	9.1
Clear Lake (24)	8.8
Burnt Pond (31)	8.3
Lake Wauberg (32)	7.4
Lake Newnans (17)	7.1
(c) MESO-EUTROPHIC GROUP	(4.0-6.9)
Unnamed 25 (25)	6.4
Lake Harris (36)	6.3
Unnamed 27 (27)	5.8
Cooter Pond (5)	5.3
Lake Lochloosa (14)	5.2
Lake Tuscawilla (33)	4.8
Calf Pond (19)	4.6
Orange Lake (15)	4.3
Lake Mize (18)	4.2
(d) OLIGO-MESOTROPHIC GROUP	(2.0-3.9)
Lake Superior*	3.7
Watermelon Pond (29)	3.6
Lit. Orange Lake (9)	3.4
Lake Weir (39)	3.3
Palatka Pond (16)	3.2
Lake Elizabeth (6)	3.2
Unnamed 10 (10)	3.2
Beville's Pond (26)	3.1
Lake Meta (21)	3.1
Lake Jeggord (12)	2.8
Long Pond (30)	2.8
Lake Moss Lee (11)	2.8
Lake Clearwater (7)	2.6
Lake Altho (4)	2.5
Hickory Pond (3)	2.5
Lake Santa Fe (1)	2.5
Lake Suggs (51)	2.3
Lake Lit. Santa Fe (2)	2.3
Lake Adaho (48)	2.2
Wall Lake (46)	2.1
Lake Winnott (53)	2.0
(e) OLIGOTROPHIC GROUPS	(< 2.0)
Still Pond (13)	1.9
Kingsley Lake (40)	1.9
Lake Geneva (44)	1.8
Lake Tahoe*	1.7
Lake Gallilee (55)	1.6
Lake Anderson-Cue (50)	1.5
Swan Lake (45)	1.5
Lake Brooklyn (43)	1.5
Lake McCloud (49)	1.5
Cowpen Lake (54)	1.5
Long Lake (52)	1.3
Sand Hill Lake (41)	1.3
Magnolia Lake (42)	1.3
Lake Santa Rosa (47)	1.3

[a] Lake number in parentheses

*Included for comparison

In order to determine logical groups of lakes whose members possess similar trophic state characteristics the fifty-five lakes were subjected to a cluster analysis considering the seven trophic indicators. The principles and methods of cluster analysis are described by Sokal and Sneath (1963). The hierarchal clustering patterns (dendrograms) are shown in Figure VII-13. One dendrogram is for the colored lakes and the other for the relatively clear lakes. (It was found for Florida lakes that fundamental distinctions could be made between lakes on the basis of organic color as suggested by Hansen (1962)). The value of the objective function on the abscissa of the dendrograms is used as a measure of similarity. In general, an increase in the value of the objective function at which a function is made represents a decrease in similarity among lakes of the newly formed group, thus lakes of greatest similarity are joined first and so on.

Several groups of lakes were interpreted in terms of classical trophic-state nomenclature as: Groups 1, 2, and 3 combined - oligo-mesotrophic, Groups 4, 5, and 6 combined meso-eutrophic, Group A - oligo-trophic, Group B - mesotrophic and Group C - eutrophic. The vertical dashed lines in Figure VII-14 were used for the discriminant analysis phase of the studies.

Using the groups of lakes delineated by the cluster analysis, five tentative TSI ranges were separated and interpreted. These ranges and groups are indicated in Table VII-11.

Some features of the TSI ranking in Table VII-11 deserve mention. Lake Alice, a lake with profuse growth of water hyacinths, has been ranked as hypereutrophic whereas on the basis of plankton productivity alone, it may well be considered as being oligotrophic. However, in the TSI, the high nitrogen, phosphorus, and conductivity indicator values were sufficient to counteract the low primary production and chlorophyll a indicator values. Anderson-Cue Lake (as previously discussed) has been subjected to artificial nutrient enrichment for three years, but has demonstrated little response with respect to the seven trophic state indicators, with the exception of chlorophyll a. As previously pointed out the lake has responded to increased periphyton growths. Because none of the seven indicators are sensitive to this response, the lake still registers a low TSI (1.5), which is identical to the TSI of McCloud Lake (the control).

The TSI formulated for Florida lakes appears to apply reasonably well in ranking other lakes; for example, Lake Tahoe, Lake Erie, and Lake Superior have been positioned where one might expect them to fall. The TSI, undoubtedly requires further testing and refining and it may well be that some trophic state indicators could be added or deleted from the index formula |Equation (1)|. However, the multivariate methods used for deriving the TSI and for grouping lakes seem most logical and hold considerable potential as tools for studying other aspects of the eutrophication process.

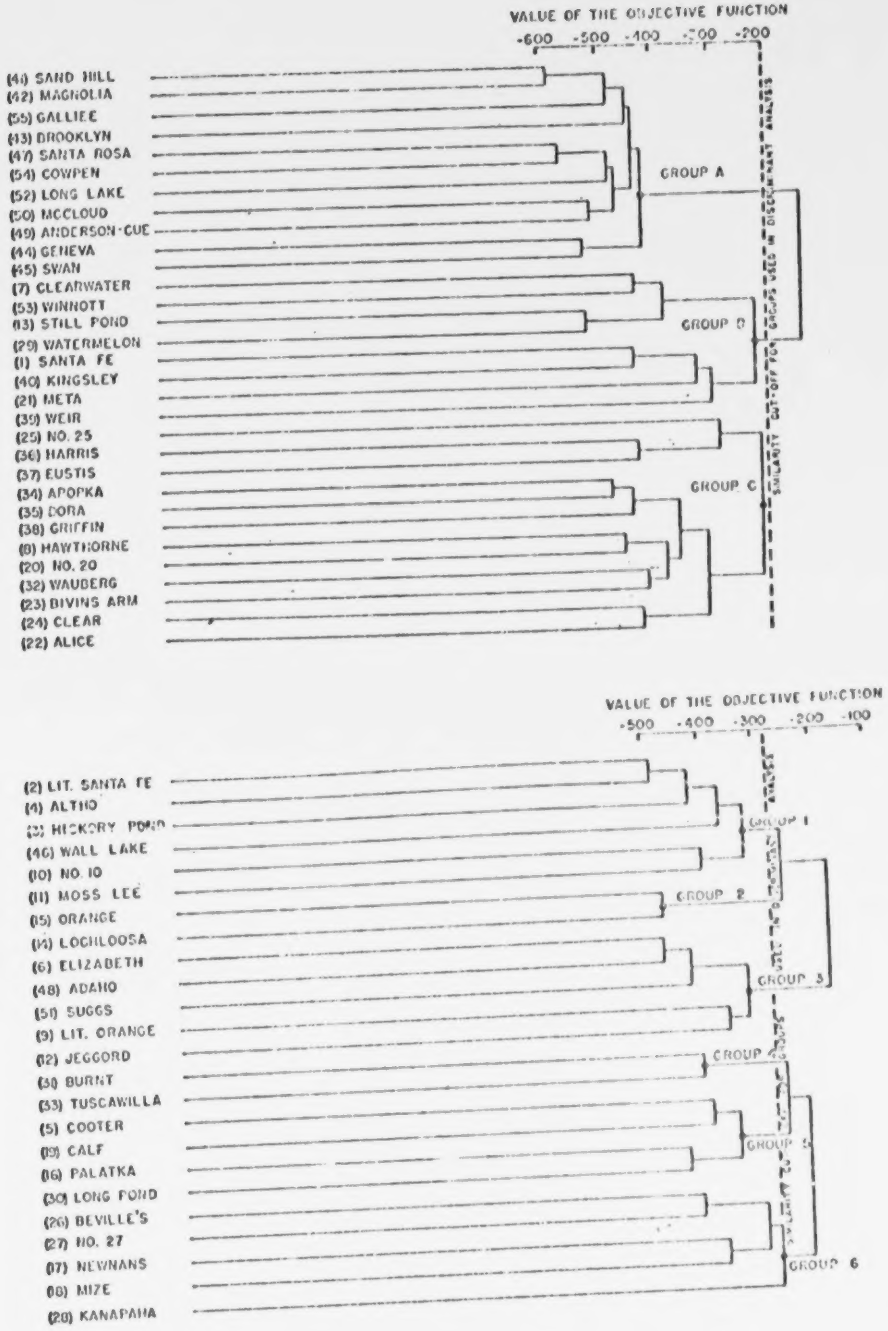

FIGURE VII-13

DENDOGRAM OF COLORED (UPPER) AND CLEAR (LOWER) LAKES CLUSTERED WITH RESPECT TO SEVEN TROPHIC INDICATORS

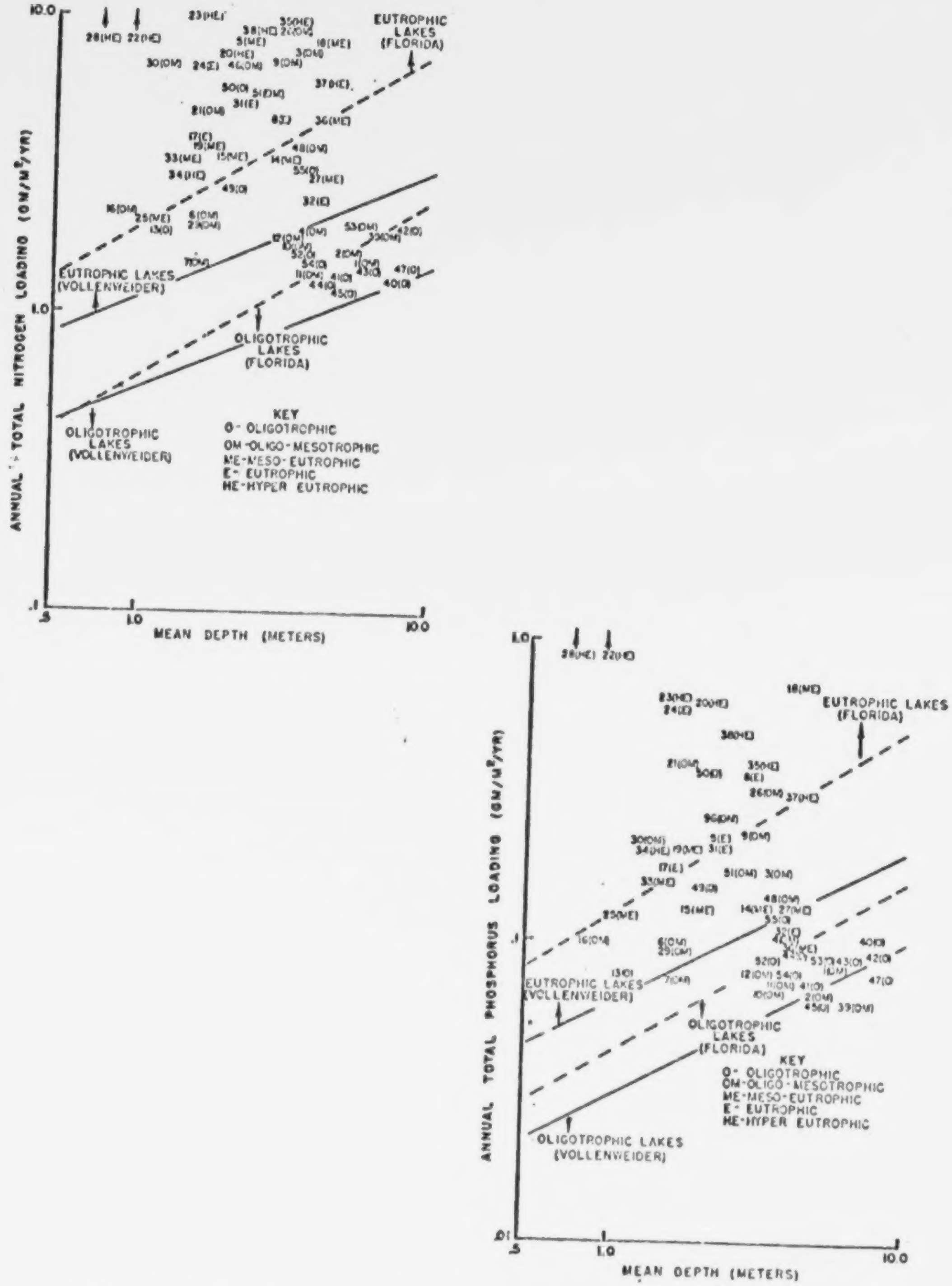

FIGURE VII-14: ANNUAL NITROGEN (UPPER) AND PHOSPHORUS (LOWER) LOADING RATES VERSUS MEAN DEPTH FOR THE FIFTY-FIVE LAKES

Trophic State and Nutrient Budget Relationships

In another phase of the eutrophication studies, partial nitrogen and phosphorus budgets were calculated for each of the fifty-five lakes. Literature values for the relative contributions of nitrogen and phosphorus from the various sources were used in the budget calculation. [For a detailed description of the calculations see Shannon (1970)]. As a whole hypereutrophic and eutrophic conditions were associated with high nitrogen and phosphorus loadings. The relationships between mean depth, lake trophic state and nitrogen or phosphorus loadings are expressed graphically in Figure VII-14. The approach is identical to that taken by Vollenweider (1968) and his oligotrophic and eutrophic areas are labeled and denoted by solid lines. Lake coordinates with respect to mean depth and nitrogen or phosphorus loading are denoted by the lake number (Table VII-11) and each lake's trophic state (from TSI ratings of Table VII-11) is given in parentheses. It appeared that Vollenweider's critical loading areas were too low and that Florida lakes were able to assimilate more nitrogen and phosphorus than suggested by Vollenweider before becoming mesotrophic or eutrophic. Accordingly regions more applicable to Florida lakes were delimited by dashed lines and labeled.

As methods of evaluating nutrient budgets and determining limiting nutrients become more concise diagrams such as those in Figure VII-14 should offer an avenue for predicting the trophic state of a lake for a given nutrient budget.

SECTION VIII

ACKNOWLEDGEMENTS

Special thanks go to Mr. Carl Swisher of Melrose on whose property the research lakes are located. Without the availability of these lakes, the project field work would have been impossible. The cooperation of Mr. Swisher will, we feel, shorten the time for the accumulation of knowledge adequate to cope with the serious problems of rehabilitating many eutrophic lakes in Florida. Special thanks also go to Colonel Harold Ashley of Melrose for his untiring efforts on behalf of the project. Colonel Ashley, a former member of the State of Florida Game and Fresh Water Fish Commission is a dedicated conservationist who leaves no stones unturned in his efforts to see that Florida's natural resources are not destroyed.

During the progress of this study many agencies and individuals rendered essential and valuable assistance and advice. Many technical reports, papers and communications were contributed which provided important background material for the staff. The following list illustrates some of the sources from which cooperation was received.

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FEDERAL AGENCIES

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Environmental Protection Agency
Office of Water Resources Research
Geological Survey

STATE AGENCIES

Trustees of the Internal Improvement Fund
Game and Fresh Water Fish Commission

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SECTION IX

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SECTION X

PUBLICATIONS

Shannon, E. E. 1970. Eutrophication-trophic state relationships in north and central Florida lakes. Dissertation presented to the Graduate Council of the University of Florida.

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16. Abstract

A small Florida lake has been receiving a regimen of nutrient addition equivalent to 500 mg/m^3-yr N and 43 mg/m^3-yr P since 1967. Data has been accumulated through 1969. The effect on the lacustrine ecosystem of various biogenes includes production by primary producers, species diversity of plankton and certain production estimates at the secondary trophic level using natural populations of planktivorous fish. Plankton production using isotopic carbon is ca. 58 grms/m^2-yr. Species diversity is slowly changing to a mixed chlorophycean and yellow-green. Biomass of benthic green filamentous types has increased slightly. Nutrient addition has had little influence on zooplankton production.

Related studies on 53 other regional lakes have been done using a multi-dimensional hybrid concept as defined by several trophic state indicators. This trophic state index has provided a means for ranking the lakes on an arbitrary scale. Cluster analysis utilizing pertinent characteristics resulted in classification of other lakes.

Land use patterns and population characteristics were determined photographically and N and P budgets estimated. Using multiple regression and canonical analysis, several significant relationships were found between lake trophic state, lake basin, land use, and population characteristics. In general, trophic state of lakes can be expressed as a simple relationship incorporating N and P influx rates.

17a. Descriptors

*Eutrophication, *Limnology, *Mathematical Model, *Essential Nutrients, *Primary Productivity, Water Quality, Trophic Level, Aquatic Algae, Fish Populations

17b. Identifiers

Anderson-Cue Lake
Melrose, Florida

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